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TERMINAL AREA DELAY AND FUEL CONSUMPTION ANALYSIS.(U)
JAN 79 A G HALVERSON, G JOLITZ

UNCLASSIFIED FAA-NA-78-40 FAA-EM-78-20 NL

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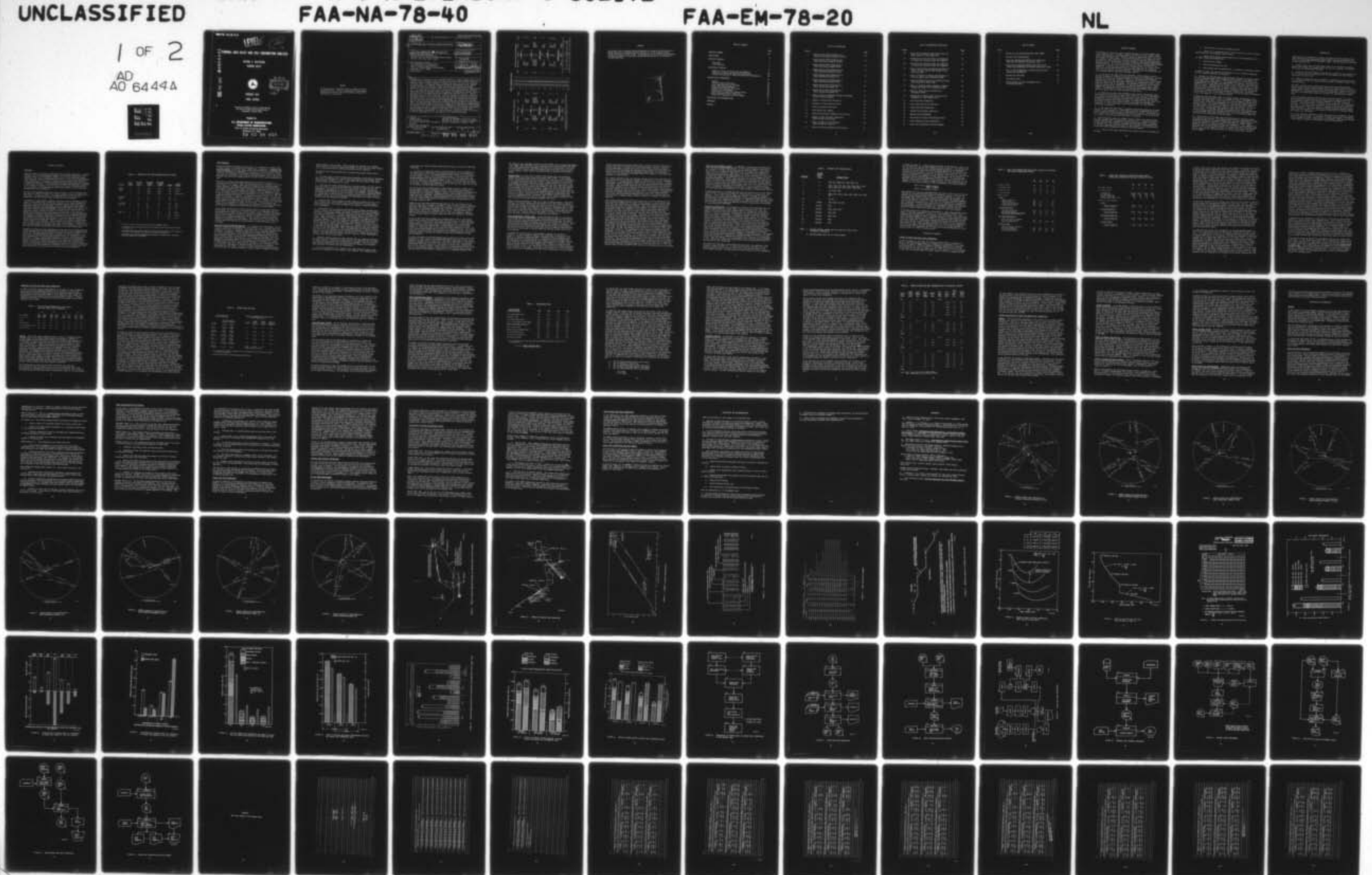

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TERMINAL AREA DELAY AND FUEL CONSUMPTION ANALYSIS

ARTHUR G. HALVERSON

GORDON JOLITZ

JANUARY 1979

FINAL REPORT

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office of Systems Engineering Management
Washington, D.C. 20590

79 02 08 038

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18 19

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-EM-78-20		

4. Title and Subtitle
6 TERMINAL AREA DELAY AND FUEL CONSUMPTION ANALYSIS,

5. Report Date
11 JAN[redacted] [redacted]79

6. Performing Organization Code

7. Author(s)
10 Arthur G. Halverson [redacted] Gordon Jolitz

8. Performing Organization Report No.
14 FAA-NA-78-40

9. Performing Organization Name and Address
Federal Aviation Administration
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
075-725-250

13. Type of Report and Period Covered
9 Final rept.
Aug[redacted] [redacted]77—Aug[redacted] [redacted]78,

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Aviation Administration
Office of Systems Engineering Management
Washington, D.C. 20590

14. Sponsoring Agency Code
12 123p.

15. Supplementary Notes

16. Abstract

The purpose of this project was to develop estimates of excess mileage flown in the terminal area, to estimate excess fuel burn due to air traffic control (ATC) delay maneuvers, and to develop a method to analyze the effect of future ATC concepts to reduce delay. The National Aviation Facilities Experimental Center (NAFEC) derived first-order estimates of delay and excess fuel consumption through analysis of track data recorded online by the Advanced Radar Terminal System (ARTS III). The data base for this initial effort was collected during the 1974-1975 time period from the Chicago, Miami, Los Angeles, and Washington terminal areas in conjunction with the ATC/Airborne CAS Compatibility Analysis project. Results show that the use of ARTS track data to derive estimates of delay and excess fuel consumption proved to be an effective approach, provided appropriate processing and manual review of the data are effected. Of the four terminal areas studied, only the data from the Chicago O'Hare airport (ORD) were sufficiently representative of delay-producing conditions to warrant credible estimates of annual delay costs. The average delay for 635 arrival tracks in the ORD data was approximately 10 minutes with an estimated excess fuel consumption of approximately 1,055 pounds (157 gallons) per track, Simple extension of these data to an annual basis yields delay and excess fuel consumption in the order of 2.5 million minutes and 40 million gallons, respectively. At current prices, these delay costs to the users at ORD are estimated to be in the range of 33 to 40 million dollars.

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17. Key Words	18. Distribution Statement
Terminal Area Path-Stretching Vectors Air Traffic Control (ATC) Procedures Holding Excess Fuel Consumption	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	118	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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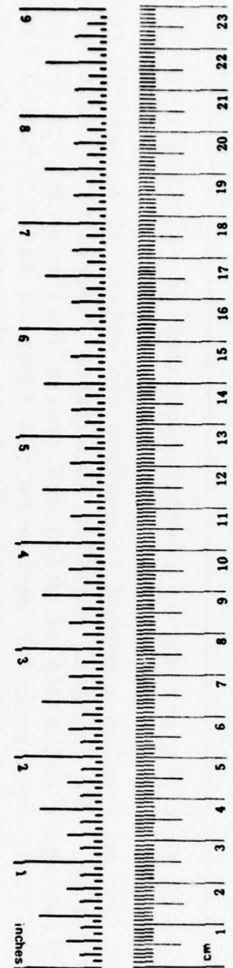
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

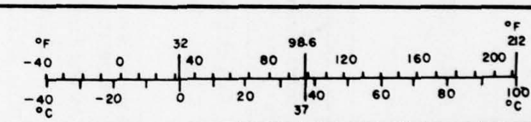
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The authors wish to express sincere appreciation to Messrs. Richard Soper and Thomas Choyce of the Analysis Branch, ANA-220, for their diligent efforts during the conduct of this study. In particular, the software system developed by Soper and Choyce will have ever increasing application in the analysis of field-derived data.

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EXECUTIVE SUMMARY

The purpose of this project was to develop estimates of excess mileage flown in the terminal area, to estimate excess fuel burn due to air traffic control (ATC) delay maneuvers, and to develop a method to analyze the effect of future ATC concepts to reduce delay. The results discussed in this report are from an analysis of ARTS track data collected during the 1974-1975 time period as a data base for the ATC/Airborne Collision Avoidance System (ACAS) Compatibility Analysis project. The data base consists of 48 hours of Advanced Radar Terminal System (ARTS) tracks; 12 hours each from Chicago, Miami, Los Angeles, and Washington. These data were collected in accordance with the criteria established for the ATC/ACAS analysis which were not completely in consonance with criteria required for delay analysis. Regardless of this limitation, the study yielded several significant findings, such as:

1. It was found that ARTS track data provides a viable medium to derive credible estimates of terminal area delay and excess fuel consumption. However, raw data as recorded by the ARTS computers are characterized by anomalies, spurious data, and other vagaries. Therefore, the process used to derive these estimates should provide for manual intervention at appropriate points; otherwise, the results may be misleading. The methodology applied in this project permitted manual review, evaluation, and editing of ARTS track data. Human judgment was applied in areas where decisions through program logic would be suspect. The methodology proved to be effective and economical and should have broad application in future analysis of ARTS data.

2. In addition to excess fuel consumption that results from holding, path-stretching, and speed control delay, other sources of excess fuel consumption were revealed from analysis of ARTS track data. These include excess route mileage due to local procedures and increased flight time and fuel flow due to premature descent from cruise altitude. In connection with the latter, the data were collected before profile descent procedures were implemented (reference 1). This, obviously, should have an effect on that source of excess fuel consumption.

3. It was found that when delay is required, the proper application of speed control and early descent is a fuel-efficient method of absorbing the delay. However, speeds requiring the use of flaps should be avoided, if possible, and early descent from cruise altitude should not be a matter of routine practice, but, rather, should be used only when delay is required.

4. Rigid procedures, where an attempt is made to absorb all delay by high-altitude holding, were not supported by this analysis. However, efforts to develop fuel-efficient scenarios to absorb delay are encouraged. As inputs to these efforts, the following strategies are provided, in descending order of priority, depending upon the amount of delay required, the predictability of the ATC system, navigational accuracy, and other factors:

a. Reduced speed while descending from enroute altitude to metering fix altitude,

b. Reduced speed at enroute cruising altitude,

c. Descent to an appropriate lower cruising altitude to effect further speed reduction (this requires further study),

d. Reduced speed between the metering fix and the approach gate, but not below clean-flap configuration,

e. High-altitude holding,

f. Path-stretching vectors, and,

g. Lower speeds near the approach gate if needed for fine-grain control.

It should be noted that the above strategies are not in complete consonance with the scenarios depicted in reference 2.

5. The need for fuel-efficient delay-absorbing strategies is clearly evident from the delay and excess fuel consumption data derived in this project for the Chicago O'Hare (ORD) airport. The average delay for the 635 ORD arrival tracks analyzed was computed to be approximately 10 minutes. The excess fuel consumption due to this delay was estimated to be 1,055 pounds (lb) (157 gallons) per track. Assuming that the current traffic levels at ORD are at least equal to those in the data base, an annual estimate of delay and excess fuel consumption for arrival aircraft at ORD can reasonably be placed in the area of 2.5 million minutes and 40 million gallons, respectively. At average 1978 prices, the cost of this delay to the users of the ATC system is estimated to be in the range of 33 to 40 million dollars.

Although the data from Miami (MIA), Los Angeles (LAX), and Washington (DCA) produced some enlightening results, no attempt was made to extrapolate annual estimates from these data. It was felt that the data samples from these airports were not sufficiently representative of the periods during which delay normally occurs. Also, annual estimates at these airports would require a thorough analysis of traffic loads, weather, and other factors. At ORD, on the other hand, traffic generally remains at high levels from 9 a.m. to 9 p.m., daily. In addition, the ORD data samples used in this analysis were collected during periods of instrument flight rules (IFR) conditions as well as visual flight rules (VFR) conditions and, also, the principal runway configurations were represented in the data base.

6. The criteria to be followed when collecting data for delay and excess fuel analyses are critical. The samples should include a representative range of weather conditions and runway configurations and each sample should be of sufficient duration to capture the oscillating effect of traffic demand (peaks and valleys) on delay and excess fuel consumption. Also, terminal area delay may start to accrue while aircraft are still well into the enroute area. Therefore, for a more complete analysis of terminal area delay, data should also be collected from selected sectors of the air route traffic control center (ARTCC).

INTRODUCTION

This project was established to support the Federal Aviation Administration (FAA) Advanced System Engineering Program (ASE) which was formulated by the Office of Systems Engineering Management (OSEM). Specifically, the objectives of this work were to:

1. Develop a data base of actual miles flown in the terminal area versus nominal and minimum route lengths which can serve as a measure of efficiency for future ATC system design concepts;

2. Derive first-order estimates of excess fuel consumed in the terminal area due to holding, path-stretching vectors, ATC procedures, and other factors associated with delay; and

3. Develop a methodology for the analysis of terminal area delay and excess fuel consumption which can support advanced concept development efforts on an as-needed basis.

Initially, the work was to include the enroute area and, where possible, actual runway-to-runway flight mileages were to be compared with fuel-conservative, direct routes as defined in the ASE Program Plan. However, due to the magnitude of the requisite data collection and reduction efforts, the scope of the effort was subsequently reduced to include only representative terminal areas.

It was the general consensus that the best source for analysis of terminal area mileage and delay was track data being recorded online by ARTS III. It was recognized, however, that effective analysis of the ARTS track data requires a substantial amount of computer software that was not available at the time. As an initial step, therefore, it was decided to use an available data base of ARTS tracks as a vehicle to develop the required software and other methodology. This data base was developed during an ATC/ACAS Compatibility Analysis (reference 3) and consists of ARTS data from Chicago, Miami, Los Angeles, and Washington.

This report discusses estimates of delay and excess fuel consumption derived during this initial phase. In addition, a general description of the methodology developed to conduct these analysis is provided. Detailed descriptions of the computer software is contained in separate documentation.

METHOD OF APPROACH

DATA BASE.

With the advent of ARTS and an associated data recording capability, it became possible to perform comprehensive analysis of real world operations in the terminal areas. It is recognized, however, that a data collection program designed to meet specific analytical objectives is a costly and time-consuming task. Moreover, for a variety of reasons, data recorded by ARTS require a considerable amount of processing and editing before being effectively applied to operational analyses. In the interest of economy and expediency, therefore, it was decided to use data for this project that had been collected earlier for the purpose of investigating the interaction between the ATC system and a proposed ACAS (see reference 3).

The data base developed during that study, referred to as the "Field-Derived Data Base," or FDDB, had many of the features needed to meet the objectives of this study. As shown in table 1, the FDDB consists of 48 1-hour data samples--12 each at Chicago, Miami, Los Angeles, and Washington.

In addition to being readily available, this data base had undergone several levels of processing, most of which is required for any type of analysis of ARTS data. Track data had been smoothed between beacon acquisition points, missing altitude data had been added, and most anomolies had been removed. There were, however, some disadvantages in using the FDDB for this study. The data were collected during the 1974/1975 time period and therefore may not completely reflect current procedures and traffic loads. Also, the data samples were selected to meet the analytical objectives of the ATC/ACAS study which were not completely consonant with delay and fuel consumption analysis. For example, more periods when delay is expected to occur, such as prolonged IFR conditions, would have been desirable. For delay analysis, samples of longer than 1-hour duration are needed to capture the effects of oscillating traffic demand on the terminal. Also, delay due to terminal conditions may start to accrue while aircraft are still under center control. Therefore, for more complete analysis of terminal area delay, it is necessary to also collect data from the enroute sectors which feed traffic into the terminal area.

Regardless of these and other limitations, it was felt that the FDDB provided a good starting point for investigating delay and excess fuel consumption that result from many interrelated factors in terminal air traffic control. In particular, the FDDB offered an ideal instrument for the development of computer programs and other methodology needed to conduct a credible analysis of these data. Further, although many problems had already been eliminated, analysis of the FDDB revealed that reduction of delay data from ARTS tracks without provision for manual intervention could yield highly questionable results. Accordingly, the process developed consists of a series of sequential steps, where each step provides the capability for manual interface with computer processing of the track data (see "Description of Methodology").

TABLE 1. CONTENTS OF THE FIELD-DERIVED DATA BASE (FDDB)

LOCATION	NO. OF 1-HOUR SAMPLES	AVG. HOURLY ARRIVAL RATE	AVG. HOURLY DEPARTURE RATE	AVG. HOURLY OPERATIONS RATE	WEATHER	ARRIVAL RUNWAY(S)
Chicago O'Hare (ORD)	3	66	Note 1	Note 1	IFR	14L/14R
	3	68	Note 1	Note 1	VFR	14L/14R
	6	66	Note 1	Note 1	VFR	27R/32L Note 2
Washington National (DCA)	6	30	26	56	VFR	36
	6	29	26	56	VFR	18
Los Angeles Intl. (LAX) Note 3	3	33	40	73	IFR	24/25
	3	36	38	34	VFR	24/25
	3	33	38	71	VFR	6/7
Miami Intl. (MIA)	6	31	28	59	VFR	9L/9R
	3	32	22	54	VFR	27L/27R
	3	29	23	52	Note 4	Note 4

Note:

1 Departure load was not a factor at ORD, due to use of independent runways.

2 In one sample, aircraft were using 27R/27L for the first half of the hour, then the 27L traffic was changed to 32L.

3 An additional three 1-hour set was collected at LAX for a particular ATC/ACAS probe. Because the operations rates were typically low, they were not included in the analysis.

4 These samples were taken when thunderstorms were reported in the terminal area. Direction of landing was changed twice in one sample.

DELAY MEASURES.

Before discussing the results of this study, it is important to clarify what is meant, herein, by "delay" and by "excess fuel consumption." Webster's New World Dictionary states that "delay implies the interference of something that causes a detainment or postponement." As applied to arrival aircraft (departures were not analyzed), the dictionary interpretation of "delay" would infer that delay is the result of one or more constraints imposed on the aircraft's movement that causes the landing time to be later than it would otherwise have been.

There are, of course, many constraints which cause arrival aircraft to encounter delay, several of which are associated with the operation of the aircraft itself. For example, cabin pressure management may preclude optimum descent gradient, and passenger comfort may limit aircraft maneuvering which could increase flying time. Other constraints causing delay can be the result of weather, terrain, noise abatement procedures, vortex phenomenon, and the like. Of primary concern in this study, however, are the constraints imposed by the ATC system during the normal performance of its mission--i.e., safe and expeditious movement of traffic. It should be pointed out that it is not the intent in this work to judge the performance of the ATC system. The sole purpose, on the other hand, is to provide objective data on how much delay accrues under differing circumstances and, further, to produce estimates as to how much excess fuel is consumed as a result of such delay. In this context then, "excess fuel consumption" is simply the fuel required over and above that which would have been consumed had the delaying constraint not been imposed.

In the normal course of air traffic control, there are three basic methods to effect delay: (a) holding in a racetrack pattern at a navigational fix, (b) path-stretching by radar vectors, and (c) speed control. Normally these delaying measures are applied in various combinations, depending upon local procedures, traffic demand, and many other factors. However, since each method impacts fuel consumption differently, it was decided to partition delay into components associated with each method. With this approach, the results can be more effectively applied in the development of fuel-conservative delay strategies.

DELAY DUE TO PATH-STRETCHING VECTORS. In a terminal radar environment, arrival aircraft normally do not navigate over a prescribed (i.e., charted) route from terminal entry point to touchdown. From feeder fix to the final approach course, navigation is primarily affected through radar vectors (headings) issued by air traffic controllers. From entry point to the feeder fix, navigation may be along a charted airway or very high frequency omnirange/tactical air navigation (VORTAC) radial, or may also be accomplished by vectoring. Moreover, radar vectors perform a dual function, i.e., navigation and separation. When separation requirements result in an increase in flying distance, the corresponding action is referred to as "path-stretching." Obviously this results in added flying time (i.e., delay) and an increase in fuel consumption; therefore, realistic measurement of path-stretching mileage was an essential requirement for this study. In order to derive this path-stretching distance, it was necessary to establish baseline routing by which to compare the actual

track distances from the FDDB. These routings are referred to as "nominal routes" which, in a general sense, approximate the paths aircraft would normally fly if path-stretching for separation purposes were not required.

The ground rules and procedures used in constructing nominal routes were as follows:

1. The start point for each arrival route (departure routes were not developed) was on the circumference of a circle which was centered at the primary airport and which had a radius of 55 nmi. It was found that the initial track point would normally lie inside such a circle.

2. There were two runway configurations in the data samples for each terminal area (see table 1), and the start point was normally the same for both configurations. The location of the start point on the circular boundary was determined by knowledge of the arrival traffic flow routings. This information was gained from (a) preferred route listings in the Airman's Information Manual, (b) observation of plotted tracks, (c) operations manuals and other facility documents, and/or (d) a priori knowledge and experience with traffic flows and procedures at the terminal of interest.

3. From the entry point, nominal routings normally proceeded directly to an inner (feeder) fix. It was found that, for the most part, the same feeder fixes were used for both runway configurations; however, observed exceptions were accommodated.

4. From feeder fix to the runway, the nominal route geometry depended upon several factors, such as weather conditions, predominate aircraft performance, the angular relationship between the feeder fix and the final approach course, and other considerations. In general, appropriate geometry from feeder fix to the runway could best be derived through repeated observations of plotted tracks. Where necessary in the design, the performance of commercial jet aircraft was assumed. It was also assumed that instrument landing system (ILS) navigation was used on the final approach, regardless of the weather (DCA "River" approach to runway 18 was an exception). However, the point of turn-on to final varied from airport to airport. On occasion, such as the parallel 14 approaches at Chicago O'Hare (ORD), different turn-on points were required between IFR and VFR conditions. When a downwind/base leg (trombone) pattern was called for, the downwind leg was constructed parallel to, and 4 to 4.5 nmi abeam of, the final approach course. The base leg in a trombone pattern permitted at 30° intercept to the final approach course at a point approximately 500 feet below the ILS glide slope.

5. Alternate nominal routes for light aircraft were not constructed because (a) except for DCA, relatively few were found in the sample and (b) the impact of light aircraft on excess fuel consumption was minimal. When the tracks of light aircraft deviated too far from the prescribed nominal, the track data were eliminated from delay and fuel computation.

6. Due to an occasional short turn-on to the final approach course, track lengths were sometimes less than nominal route lengths. Such "negative path-

stretching" was reduced through design modifications, but never was completely eliminated.

7. In order to capture the effect of local procedures on route lengths, an alternative route, referred to as "minimum approach route," was constructed for each nominal route. The minimum approach route started at the same point on the boundary circle as the corresponding nominal. From that point, the minimum approach route was constructed so as to reflect the most direct path for an ILS approach to the nearest runway in use. In this design, turn radii of jet aircraft were accommodated and, in addition, the route could not overfly the airport. Terrain, noise abatement, and the like were not taken into account in the design of minimum approach routes.

As can be seen from the "Description of Methodology" section, nominal routes were developed through an iterative process. Each configuration would be checked against a sufficient number of tracks to ensure adequate representation. Although this was primarily a judgment process, route mileage versus track length was also considered. When excessive negative path-stretching occurred, track plots were analyzed to determine whether (a) the nominal should be modified, (b) certain tracks should be dropped from further consideration, or (c) no changes should be made.

Nominal routes that were ultimately developed for the four airports in the data base are shown on figures 1 through 8. These include all routes developed except (a) VFR routes for ORD runway 14L approaches, (b) alternate routes for ORD runway 27L approaches during the dual, 32L/27R configuration, (c) Midway (MDW) routes, and (d) Fort Lauderdale (FLL) routes. Initially MDW and FLL nominals were constructed, and delay and fuel data were computed. However, due to the small number of tracks, these data were not included in the final results.

As can be seen from these nominal route configurations, many of the nominal routes nearly follow the most direct path from entry point to final approach course. This is reflected in the annotated distance data. On the other hand, minimum approach routes which differ substantially from the corresponding nominal are depicted in dashed lines. A good example is route 5B at MIA (figure 4). From track data it was found that, when landing west at MIA, aircraft through SERPA normally were vectored for an approach to 27L. The closest runway for this traffic was 27R; therefore, the minimum approach route was constructed as shown to capture the effect of these local procedures on excess fuel consumption.

To derive the amount of path-stretching delay incurred by a track, it was first necessary to find a point on the associated nominal route that closely corresponds to the start point of the track. This was accomplished in the computer program by swinging an arc through the track start point until it intersects the nominal route (see figure 9). The center of the arc was a prespecified point in the close-in pattern, normally where the minimum approach route merges with its corresponding nominal. That portion of the nominal route from the intersect point to the runway is referred to as a "comparable nominal route."

The length of the comparable nominal is called "CNOM," and the difference between track length (TRK) and CNOM is the resulting path-stretching mileage (TRK-CNOM). In the CNOM computations, adjustments were made for turning radii. Note also that when CNOM is greater than TRK, negative path-stretching mileage results. In the summary of data, negative path-stretching is treated in an algebraic manner.

HOLDING DELAY. In this study, terminal area holding delay was derived by manually recording holding times from plotted ARTS tracks. If the holding pattern was entered after the first data point of the track, then the duration of the complete holding delay was recorded. These holding data are referred to as type A holding and generally reflect holding delay that occurred after handoff from the center. If, on the other hand, the first data point of the track revealed that the aircraft was holding at that time, only the remainder of the holding delay could be recorded. Unless the time of the first data point was equal to the start time of the sample hour, it was obvious that the aircraft had been holding for an undeterminable amount of time while under control of the center. In either case, these incomplete holding delays were recorded as type B holding. Obviously, this yielded results substantially less than what actually occurred at the time, and it therefore points out the need for enroute data when deriving terminal area delay.

Figure 10 depicts examples of type A and type B holding patterns. With type A holding, the computer removes holding distance from track length by making a straight-line connection between the "time-in" point with the "time-out" point. Altitude data at these two points were also saved for subsequent use. In the case of type B holding, only "time-out" was manually extracted, and all track data prior to that point were stored as holding delay. Track length was computed from the "time-out" point to the runway. Altitude at the "time-out" point was used to represent type B holding pattern altitude.

EARLY DESCENT/SPEED CONTROL DELAY. During the analysis phase of the project it was found that (a) considerably more level-flight mileage was flown by aircraft in the data base than was needed for path-stretching delay, (b) level-flight altitudes (weighted averages) were well below 10,000 feet, and (c) level-flight mileage and speeds varied substantially from terminal to terminal. In the interest of deriving data from the FDDB relative to the profile descent program (reference 1), which was instituted after the FDDB was collected from the field, it was decided to include speed and vertical profile data in the final results.

To appreciate the delay due to early descent, consider the profile on figure 11. In that schematic, descent from 35,000 feet is initiated 27 nmi ahead of a continuous descent gradient. Assuming standard atmospheric conditions and without considering wind, the reduction in true airspeed (TAS) from 450 knots to 290 knots results in a 2-minute increase in flying time over the 27 nmi even though indicated airspeed (IAS) remains at 250 knots. This delay would have occurred in the example shown on figure 11 solely by early descent, whether or not it was the intent of the ATC system to reduce the speed of the aircraft at that point. Obviously, level flight at the lower altitude results in more fuel consumption; but this will be discussed in a later section.

Closely intertwined with early descent delay is delay caused by speed control instructions used to facilitate the traffic management function. However, a precise measurement of delay due to both forms of speed reduction requires analysis of voice recordings and additional processing of the track data that had not been provided during the programing support phase of the project. Therefore, it was necessary to manually derive an estimate of this delay from analysis of available data.

For reasons explained later, the vertical profile of each track had been computer and stored by the computer program for subsequent use in fuel consumption computation. In developing the vertical profile for arrival tracks, a regression analysis model was applied to the altitude associated with each 30-second data point. When the model indicated that the descent gradient was less than 100 ft/nmi (parameter), the track was declared as being level at that point. A typical profile is shown on figure 12. Level-flight distance and level-flight time were accumulated and stored for each track. In addition, a time-weighted altitude was computed based on the duration at each level-flight altitude. Later, data reduction programs summarized these data into altitude bands for specified sets of sample tracks. Figure 13 depicts an example of these data summaries.

Early descent mileage was derived for a given set of data by subtracting the path-stretching mileage from the level-flight mileage. In other words, these additional level miles were not needed for separation purposes and therefore could have been flown at cruise altitude. Since level-flight distances and level-flight times were available in the summary, an average track velocity was easily derived. An estimate of delay time was derived by computing the difference in flying time over the early descent miles between the time required at average track velocity and the time that would have been required at a nominal cruise speed of 450 KTAS. Obviously, in this method the effect of speed control could not be separated from the effect of early descent. Accordingly, these delay components were combined in the final results. However, additional delay occurs during descent when aircraft have been given speed instructions by the controller. An estimate of this delay was derived by computing the difference in flying time over the descent mileage (track length minus level-flight distance) between the time required at average track velocity and the time that would have been required at an average nominal speed of 265 KTAS. (At MIA, the average track velocity over all tracks in the data sample was 271 knots.) The coarseness of the foregoing estimating method is recognized. It is felt, however, that lacking a more precise method, the data so derived from the FDDB can provide important inputs to fuel conservation techniques, such as profile descent. It is expected, for example, that the point at which descent from cruise altitude is initiated, has rarely been associated with delay. Yet, by the natural phenomenon of air density, delay occurs when aircraft are descended early, whether such delay is needed or not for air traffic control purposes. Furthermore, as will be shown later, when delay is required, early descent together with speed control is a fuel-efficient way to absorb the required delay as long as speeds below clean-flap configurations are not employed.

DELAY DUE TO PROCEDURAL ROUTING. In addition to holding, path-stretching vectors, and early descent/speed control, a fourth delay component, referred to as "procedural routing," was derived from the ARTS track data. These delay data relate to the added mileage embodied in the nominal route geometry as a result of local procedures. There are a wide range of factors involved in establishing procedural routings; however, it was not the intent in this study to assess the impact of the individual factors, nor to pass judgment on the procedures themselves. Rather, these data were derived solely to identify yet another area where fuel conservation procedures or techniques may have application. It will be seen, for example, that, while procedural routing average less than 1-minute delay per track, overall, there are a few routes within each terminal area which contribute to the bulk of the total procedural routing delay. Accordingly, improvements in this area to reduce excess fuel consumption would need only to concentrate on a limited number of identifiable factors.

As discussed earlier, a minimum approach route was constructed for each nominal route in order to capture the effect of local procedures on excess fuel consumption. In the basic nominal geometries (figures 1 through 8), minimum approach routes started from the same point as the corresponding nominal route. For individual track computations, however, a "comparable minimum approach route" distance computation (CMIN) was started at the track start point (see figure 9). The difference between CNOM and CMIN was the excess mileage delay attributable to local procedures (CNOM-CMIN).

EXCESS FUEL COMPUTATION. In an attempt to construct fuel flow models for the aircraft types found in the data base, it was found that actual fuel flow depends upon many factors, most of which were not available to the project. However, it was felt that good estimates could be derived from available data based on a few key assumptions. For example, aircraft performance manuals depict fuel flow in level flight a function of weight, speed, and altitude. Speed and altitude could be derived from ARTS tracks; however, it was necessary to make an assumption regarding weight for the particular aircraft type. Further, it was found, for the purpose of this project, that aircraft types could be reasonably grouped into categories in accordance with the number and type of engines and assumed weight. Table 2 shows the category grouping for the jet and turboprop aircraft used in the fuel consumption computation. These types accounted for over 99 percent of the usable FDDB arrival tracks. Another assumption involved fuel consumption during the descent phase of operation. For several reasons, it became necessary to disregard fuel consumed during descent and therefore base all findings on level-flight data. For example, excess fuel consumption attributable to path-stretching was derived from path-stretching mileage and a computed level-flight fuel flow rate (to be explained later). What this amounts to is the assumption that different descent gradients in the terminal area (after ARTS acquisition) have an insignificant effect on differences in fuel consumption.

The method for computing a level-flight fuel flow rate to be applied to delay mileage is shown on figure 14. It can be seen that the resultant rate is a weighted average based on aircraft type and the distance and speed at each level segment altitude. The application of these variables on fuel consumption

TABLE 2. AIRCRAFT TYPE CATEGORIZATION

CATEGORY	ASSUMED WEIGHT (lb)	AIRCRAFT TYPES
5	—	MU2, VC6, BE99, OV1, DH6, BE90, U21
6	—	YS11, G159, SW2, SW3, SW4, CV58, ND26, CC09, FA22, CV64, C2, FA27, FH22, C580, HP13
7	—	P3, C130, L188
8	—	H525, AC21, LR23, LR24, LR25, N265, T39, C500, A37
10	—	G2, FFJ
11	90,000	B737, BA11, C9, DC9
13	140,000	B727
14	220,000	B720, C135, C140
16	220,000	B707, DC8
17	320,000	DC10, L101
18	220,000	DC86
19	550,000	B747

NOTES: 1. Missing category numbers were for types not used in fuel consumption computation.

2. Assumed weights were for the arrival phase.

is shown on figure 15. A second-degree equation was developed for each of the four altitudes for the aircraft categories shown in table 2. The coefficients for the fuel flow equation were derived through application of regression analysis on the data extracted from performance manuals for the aircraft type representing each category. Two sets of coefficients were derived for commercial jet transports (categories 11 through 19). The first set, like the one shown on figure 15, represents a no-flap configuration, and the second set represents various flap settings as a function of KIAS. The flap data were obtained from the United Airlines Office, Denver, Colorado (reference 6). An example of the effect of flaps is shown on figure 16. Indicated airspeed was computed by using track velocity as KTAS and applying the following formula:

$$\text{KTAS} = \text{KIAS} \times \frac{68320 + 0.293\,Z}{6832 - 0.707\,Z}$$

where Z is altitude in feet.

The weighted fuel flow rate described above was used to derive excess fuel consumption due to path-stretching delay and procedural routing. For fuel consumption during holding delay, however, a different approach was taken. It was assumed that aircraft held at optimum holding speeds and therefore fuel consumption would be in accordance with data published in performance manuals such as that shown on figure 17. These data are normally given in pounds per hour; therefore, holding duration was used in fuel computation as opposed to holding distance. In this computation a second-degree equation was used where the independent variable was altitude (Z). Regression analysis was also applied to derive holding fuel flow coefficients for each type category.

In deriving excess fuel consumption attributable to early descent/speed control delay, it was again necessary to resort to an approximation method. From analyzing fuel consumption for jet aircraft in the data base, it was found that a good average estimate of fuel consumption (lb/nmi) at cruise altitude is about half the average computed for the tracks at the weighted level-flight altitude. Therefore, after fuel attributable to path-stretching was subtracted from the total fuel consumed in level flight (634,988 lb in figure 13), the difference was divided by two. These estimates were made for only the final summaries of the total data sample for each terminal area. Also, no attempt was made to derive excess fuel consumption due to delay that accrued during descent in the terminal area as a result of speed control.

DISCUSSION OF RESULTS

SUMMARY OF DELAY AND EXCESS FUEL CONSUMPTION.

An overall summary of the delay data reduced from the FDDB is presented in table 3, and corresponding excess fuel consumption attributable to this delay is shown in table 4. Figure 18 depicts a bargraph comparison of the excess fuel consumption for the four airports in the sample data together with the average arrival rate over all sample hours for each airport. It is interesting to note that the average number of usable tracks in the 1-hour samples at ORD

TABLE 3. DELAY DATA REDUCED FROM ARTS TRACKS (FIELD DATA COLLECTED FOR ATC/ACAS INTERACTION STUDY)

	ORD	MIA	LAX	DCA
Total Number of Tracks	635	217	175	212
Per-Sample Average	53	18	19	18
Total Delay Time (min)	6,160	699	568	1,038
Per-Track Average	9.7	3.2	3.3	4.9
Components of Delay:				
Holding				
Number of Tracks Held	132	3	0	6
Percent of Total	20.8	1.4	-	2.8
Total Holding Time (min)	1,128	12	-	39
Average Time Per Hold (min)	8.6	4.0	-	6.4
Per-Track Average (min)	1.8	NIL	-	0.2
Path-Stretching Vectors				
Total Delay Mileage (nmi)	6,769	773	617	1,111
Per-Track Average (nmi)	10.7	3.6	3.5	5.2
Ratio:Delay to Nominal Route (Percent)	20	6	7	9
Est. Per-Track Delay Time (min)	3.0	0.8	0.9	1.3
Early Descent/Speed Control				
(NOTE: See "Method of Approach")				
Est. Total Delay Time (min)	3,604	369	333	530
Per-Track Average (min)	4.1	1.7	1.9	2.5
Procedural Routing				
(NOTE: See "Method of Approach")				
Total Delay Mileage (nmi)	1,927	662	323	796
Per-Track Average (nmi)	3.0	3.1	1.8	3.8
Per-Track Delay Time (nmi)	0.8	0.7	0.5	0.9

TABLE 4. EXCESS FUEL CONSUMPTION REDUCED FROM ARTS TRACKS (FIELD DATA COLLECTED FOR ATC/ACAS INTERACTION STUDY)

	ORD	MIA	LAX	DCA
Total Number of Tracks	635	217	175	212
Total Excess Fuel Burn				
All Tracks (lb)	670,009	116,493	60,424	70,995
All Tracks (gal)	100,001	17,387	9,019	10,596
Per-Track Average (lb)	1,055	537	345	335
Per-Track Average (gal)	157	80	52	50
Per-Track Cost (in dol.) @ $.42	66	34	22	21
Excess Fuel Per Delay Component				
Holding				
Total--All Holding (lb)	142,350	1,238	0	3,140
Per-Hold Average (lb)	1,078	413	-	523
Path-Stretching Vectors				
Total--All Tracks (lb)	273,954	28,644	26,498	24,692
Per-Track Average (lb)	431	132	151	116
Early Descent/Speed Control				
Total--All Tracks (lb)	180,517	64,877	22,201	27,451
Per-Track Average (lb)	284	299	127	129
Procedural Routing				
Total--All Tracks (lb)	73,188	21,734	11,725	15,712
Per-Track Average (lb)	115	100	67	74

is about triple that at MIA, LAX, and DCA, even though the average arrival rate at ORD was only about twice that of the other airports. In general, this results from the fact that the traffic at ORD is highly regimented and could normally be associated with a nominal route; whereas, special treatment was frequently given to traffic at the other airports. In particular, during VFR weather and light or moderate traffic, local service and commuter flights at these airports would often land on a secondary runway or would otherwise be vectored such that association with a nominal route was not feasible. Further, since the FDDB samples were taken in 1-hour slices in time from the ARTS recordings, tracks at the beginning and at the end of each sample hour were also not usable for delay analysis. Overall, about 80 percent of the tracks in the ORD samples could be used in the analysis, and at MIA, LAX, and DCA about 60 percent of the tracks were suitable. Obviously, a data collection program, established to measure delay and excess fuel consumption, would require longer sampling periods than the FDDB and would avoid periods of light VFR traffic. In spite of the shortcomings of the sample data, however, the study yielded highly useful results concerning terminal area delay and excess fuel consumption. In particular, the findings from this study have direct application to efforts dealing with the development of fuel conservation procedures and techniques.

Of particular interest are the average total delay per track (table 3) and the average excess fuel consumption attributed to that delay (table 4). Note that, while individual delay components appear relatively small, the aggregate of these data can be considered substantial, particularly at ORD. For example, the average time in system, from ARTS acquisition to landing, was about 21.5 minutes for the 635 tracks; however, using methods previously described, nearly 45 percent of that time (9.7 minutes) was calculated to be delay. The average nominal route distance for these tracks was 54 nmi, so that without holding, path-stretching, or speed control, the average time in the system would be slightly over 14 minutes. Therefore, even discounting procedural routing delay and the added effect of early descent, a delay of 7 to 8 minutes remains. In addition to the effect on fuel consumption, absorbing this delay prior to ARTS acquisition would have the added effect of reducing the simultaneous number of aircraft under approach control by seven to nine aircraft. Obviously, the impact on center workload would depend on how and where the delay was absorbed by ARTCC.

In connection with excess fuel consumption, the average aggregate amount of 1,055 lb (157 gallons) per track at ORD appears substantial in light of fuel costs. To properly view these data in connection with the national posture on energy conservation, it is necessary to extend the estimates of excess fuel consumption to a longer time frame, such as to an annual basis. It was felt, however, that the sample data used in this project were not sufficiently representative to make a statistically valid annual extrapolation. Without belaboring the point, it seems obvious that estimates of this nature require especially designed data collection criteria. Nevertheless, to sense the order of magnitude of what the average values on table 4 project to on a annual basis, one can apply simple arithmetic to the ORD data. It was found, for example, that the present demand/capacity ratio at ORD is about the same as it was when the data used in this project were collected (1974-75). Also, inspection of the schedules in the Official Airline Guide indicates that the

demand is at a nearly continuous peak from 9 a.m. to 9 p.m. Therefore, a first-order estimate of excess fuel consumed daily by arrival aircraft during the 12 peak hours at ORD can reasonably be derived by extending the 100,000 gallons of excess fuel from the sample data (table 4) in the following manner. First, since each sample hour yielded about 48 minutes (80 percent) of usable track data, it is necessary to divide 100,000 by 0.8 to extend the 12 sample hours to 12 complete hours of operation. This computation yields an estimate of 125,000 gallons of excess fuel consumption for 12 peak hours. Assuming the sample data are sufficiently representative of the average operations at ORD during peak hours, an annual estimate of excess fuel consumption due to delays to arrival aircraft ranges from 32.5 million gallons (based on a 5-day week) to 39 million gallons (based on a 6-day week). Extending the total delay time for the ORD sample (6,160 minutes, table 3) in the same manner yields an annual estimate of from 2 to 2.4 million minutes of delay. Using an average fuel cost of 42¢ per gallon and an average direct operating cost without fuel of $10.00 per minute (reference 7, B727, extrapolated to December 1978), a range in cost to the users due to arrival delay at ORD is estimated to be from 33 to 40 million dollars, annually. It should be emphasized at this point that, when comparing these delay cost estimates with other estimates, the data from the this study did not include terminal area delay that might have accrued prior to the ARTS track acquisition point (i.e., ARTCC holding vectoring and speed control). Also, no attempt was made to derive delay and excess fuel consumption for the departure or ground operation phases of operations. Obviously, an analysis of departure tracks and of tracks in the close-in enroute area would be a natural extension of the work conducted in this study, and, together, these analyses could provide good estimates of total terminal area delay costs.

In addition to the foregoing, it would also be of interest to derive annual estimates of delay costs at other terminal areas. Such estimates were not made in this study for MIA, LAX, and DCA for two reasons. First, it was felt that the sample data did not sufficiently represent the wide range of conditions which cause delay at those airports (i.e., prolonged periods of IFR weather and/or saturated traffic conditions, etc.). Second, traffic at these airports has not reached the near steady state conditions of the 9 a.m. to 9 p.m. traffic at ORD. Therefore, an estimate of annual delay costs would require an analysis of the traffic conditions that occur throughout the year. Such an analysis was beyond the scope of this study; therefore, no attempt was made to extend the MIA, LAX, and DCA data beyond that shown in tables 3 and 4.

Concerning the delay and excess fuel consumption problem, one further point is in order. It was found in this study that a representative commercial jet (B727) would burn about the same amount of excess fuel as the average of the ORD tracks (1,055 lb) if <u>all</u> delay (9.7 minutes) were absorbed <u>while holding at 20,000 feet</u>. This does not support the argument for the postulated fuel savings of <u>rigid</u> profile descent procedures where all terminal area delay is absorbed in holding patterns at metering fixes. It does, however, support work already started, and encourages new work relative to fuel-efficient methods for consuming delay.

COMPONENTS OF DELAY AND EXCESS FUEL CONSUMPTION.

In order to provide a better understanding of the impact of fuel consumption of the various delay-absorbing methods, it was decided to partition the delay data from the ARTS tracks into the four components shown in table 3. The contribution each component makes to total delay and total excess fuel consumption at each airport in the data base is shown in table 5. Salient aspects of these data are included in the detailed discussion of each delay component that follows.

TABLE 5. RATIO OF DELAY COMPONENTS TO TOTAL DELAY AND TOTAL EXCESS FUEL CONSUMPTION

	ORD		MIA		LAX		DCA	
DELAY COMPONENT	% OF TOTAL DELAY	% OF EXCESS FUEL	% OF TOTAL DELAY	% OF EXCESS FUEL	% OF TOTAL DELAY	% OF EXCESS FUEL	% OF TOTAL DELAY	% OF EXCESS FUEL
Holding	18.6	21.2	NIL	1.1	0	0	3.8	4.4
Path-Stretching	30.9	40.9	25.0	24.6	27.3	43.9	26.5	34.8
Early Descent/Speed Control	42.3	26.9	53.1	55.7	57.6	36.7	51.0	38.7
Procedural Routing	8.2	10.9	21.8	18.7	15.2	19.4	18.4	22.1

HOLDING. Of the four delay components shown in table 5, "holding" provides the best index of the demand versus capacity relationship. However, to measure demand and the holding that results when demand exceeds capacity, it is necessary to analyze data well in advance of the point where the tracks are acquired by ARTS. Since only ARTS track data were available to this study, no estimate of terminal area demand was attempted, and the holding delay shown in table 3 consists only of the holding times that could be extracted from these tracks (see Method of Approach). In spite of this limitation, the holding delay derived from the ORD tracks is considered significant. For example, even though the arrival rate averaged 66 aircraft per hour (figure 18), about 1 in every 5 aircraft encountered holding delay. This is a good indication of the excess in demand over capacity during the sample periods and, judging by recent traffic statistics, is probably indicative of the present operation at ORD. (Obviously, this excludes the triple-arrival runway operation which has recently been introduced during suitable periods of wind, weather, and runway braking conditions.)

It is interesting to note that the ratio of aircraft that were held (20.8 percent) is about the same as the ratio of total holding fuel to the total excess fuel consumed (21.2 percent) as shown in table 5. This is due to the large amount that each hold costs in excess fuel (1,078 lb, on the average).

Regarding the holding time at ORD, it should be remembered from the Method of Approach that when aircraft had been held by the center, only the time subsequent to ARTS acquisition could be tabulated for this study. Of the 132 aircraft that were held, 87 were of this type, averaging 6.7 minutes of holding time after entry into the ARTS system. Tracks of the remaining 45 aircraft that were held were acquired prior to holding start time, which generally indicates that approach control had instructed these aircraft to hold. These tracks had an average hold duration of 12 minutes. Although one might assume that the latter duration provides a good estimate of average holding time for all aircraft that were instructed to hold (either by ARTCC or by approach control), there was nothing in the data to verify this assumption. Therefore, a more valid approach in estimating holding delay cost would be to consider system holding time as opposed to per-aircraft holding and to separate the enroute data from the terminal data. While estimates of enroute holding delay data require separate study, estimates for the ORD terminal data can be made by extending the holding delay in table 3 in a manner analogous to the approach taken for total delay, above. First, recalling that the 12 sample hours amount to about 9 actual hours of track data, then the 1,128 minutes of holding delay computes to an average of 125 minutes per peak hour, or 1,500 minutes for 12 consecutive hours of peak traffic (normal ORD operations from 9 a.m. to 9 p.m.). Simple arithmetic yields a first-order annual estimate of terminal area holding at ORD of from 390,000 minutes (for 5-day week) to 468,000 minutes (for 6-day week). Extending the excess fuel consumption at ORD due to holding delay from table 4 in a similar manner produces an annual estimate ranging from 7.4 to 8.8 million gallons.

It should be noted that the data used in this study were collected prior to the implementation of profile descent procedures. The intent of these procedures is to eliminate holding and other delay at low altitudes inside the metering fix. The fact remains, however, that when aircraft are put into holding stacks, demand on the airport has exceeded the effective capacity of the airport for some undefined period of time. With an equal demand/capacity ratio, the application of profile descent alone merely shifts the holding delay to a higher altitude. Obviously, the fuel savings by holding at higher altitudes depends upon several factors, including type and weight of the aircraft, holding speed, flap configuration, etc. An example of the effect of holding altitude is presented in table 6. For the fuel consumption of the track data, it was assumed that all aircraft held in a clean configuration. This yielded an average holding fuel flow rate of 7,917 lb/hr for the five categories shown. This rate is slightly lower (2.3 percent) than the weighted average at 10,000 feet from the UAL data (8,101 lb/hr). The difference is due, in part, to the lower holding altitudes (overall average of about 9,000 feet), and also to the no-flap assumption for the heavy aircraft. With the same distribution of holding times by type of aircraft, a weighted average of 7,105 lb/hr was computed from the United Airlines (UAL) data for holding at 20,000 feet. This is 10.3 percent less than the track average, and 12.3 percent less than the weighted average at 10,000 feet from the UAL data. For holding times of 10 minutes per hold, these differences yield 135 and 166 lb less fuel, respectively. At current fuel prices (42¢ per gallon), it is estimated that an average savings of 8 to 10 dollars for each 10-minute hold would result by

TABLE 6. HOLDING FUEL FLOW DATA

FUEL FLOW DATA FROM UNITED AIRLINES (UAL)			HOLDING FUEL CONSUMPTION FROM SAMPLE TRACKS (99.2% OF HOLDING FUEL)			
A/C TYPE (WEIGHT)	FUEL FLOW (lb/hr) (Holding @ 200 KIAS) 10,000 ft	20,000 ft	CATEGORY	HOLDING FUEL BURN (lb)	HOLDING TIME (MINUTES)	RATIO OF HOLDING TIME (PERCENT)
B737 (90K lb)	4,185 (clean)	3,865 (clean)	11	21,547	272	25.4%
B727-200 (140K lb)	7,085 (clean)	6,616 (clean)	13	61,014	483	45.1%
DC8-61 (220K lb)	11,600 (10° flaps)	9,520 (clean)	16	32,714	195	18.2%
DC10 (320K lb)	13,880 (slats)	11,060 (clean)	17	20,494	103	9.6%
B747 (550K lb)	24,500 (5° flaps)	21,200 (1° flaps)	19	5,409	17	1.6%
Weighted Average*	8,101	7,105	Total	141,178	1,070	
			Average Rate 7,917 lb/hr**			

* UAL fuel flow rates weighted by proportion of the total holding time the representative category in the sample data was held.

** Average holding altitude at ORD was approximately 9,000 feet.

holding at 20,000 feet as opposed to the holding altitudes in the ORD sample data. By applying the difference in final consumption due to holding altitude to the annual estimate made earlier, a difference ranging from 0.8 to 1 million gallons of fuel results.

The absence of any significant amount of holding at the other airports in the sample data is probably more reflective of the periods during which the data were collected than anything else. However, it can be assumed that the requirement for prior reservation for landing at DCA minimizes holding delay at that airport, except possibly during prolonged periods of IFR weather. All DCA data used in this study were collected during periods of VFR weather. Although 3 hours of the LAX data were during IFR weather, the traffic demand during these periods did not exceed the airport capacity to any noticeable degree. This was generally the case throughout the LAX sample data; therefore, it is felt that the zero holding delay as well as all other delay measures at LAX are not representative of that busy airport. At MIA, the weather, traffic demand, and multiple runway operation, together, militate against the need for holding delay. It is expected that only during seasonal periods of peak itinerant traffic will holding delay of any substantial amount be required at MIA.

PATH-STRETCHING VECTORS. As with holding, the delay due to path-stretching vectors at ORD clearly stands out over the other airports. Because of the near steady state traffic demand at ORD from 9 a.m. to 9 p.m., it is felt that the ORD data are representative of the path-stretching delay generally encountered by arrival aircraft during these 12 peak hours each day in the years when the data were collected. Data from the other airports, on the other hand, are not considered so representative, since many factors which cause delay were not a part of the data collection criteria for the ATC/ACAS study.

To more clearly perceive the significance of the ORD data, consider the fact that the average time in the system was just over 21 minutes; viz, from track acquisition to touchdown, not including holding. In this interval of time, aircraft, on the average, flew about 20 percent (10.7 nmi) further than the nominal route distance and consumed about 431 lb (64 gallons) of excess fuel. Extending these data to form annual estimates by the method previously described yields a range of 2.2 to 2.6 million delay miles, annually, and a range in excess fuel consumption of 13 to 16 million gallons. Further, the average fuel burn rate over all path-stretching delays at ORD was slightly over 40 lb/nmi or about 8,660 lb/hr. This is approximately 22 percent more than the weighted holding fuel burn rate at 20,000 feet (7,105 lb/hr) shown in table 6. Therefore, extending this difference to the annual estimate yields a savings of between 2.4 and 2.9 million gallons of fuel in favor of high-altitude holding.

It should be pointed out that this finding is not in contraposition with the discussion under "total delay," since the latter included the impact of early descent and speed control. As will be shown, these delay-absorbing techniques can be highly fuel-efficient. The difference in fuel-efficiency between

path-stretching and early descent/speed control can be seen from the data in table 5 for ORD, LAX, and DCA. At these airports, the percentage of excess fuel attributed to path-stretching is considerably higher than the corresponding percentage of delay absorbed, while the reverse is true in the early descent/speed control data. The incongruity in the MIA data is explained in the next section.

EARLY DESCENT/SPEED CONTROL. As described in the "Method of Approach," delay and excess fuel consumption attributable to early descent and speed control were derived by an estimation method due to the lack of complete information about the tracks. Regardless of this limitation, these data are relevant to the objectives of the study because the findings show that (a) unintentional delay and excess fuel consumption can result from early descent and (b) when delay is required, early descent together with speed control are fuel-efficient techniques for absorbing the required delay, as long as speed below clean-flap configuration are not employed. Further, it will also be shown that the use of speeds that require flaps is not a fuel-efficient method of absorbing delay.

The effectiveness of the early descent/speed control method of absorbing delay can be seen from the data in table 5. Except for MIA, the delay ratio is considerably higher than the excess fuel ratio. Further, at ORD, LAX, and DCA, the delay fuel burn rate due to early descent/speed control computes to 4,156, 4,010, and 3,096 lb/hr, respectively. The fuel-efficiency of this method becomes obvious when these rates are compared with the "holding" fuel burn rates in table 6. In the MIA data, a reverse trend was exhibited. It was found, however, that the average track velocity at MIA was 271 knots. This is 6 knots higher than the nominal terminal area speed used to compute speed control delay. Therefore, no delay was attributed to controller speed control instructions, leaving all delay attributed to early descent. It is not known whether such delay was intended or not, but, if intended, it would have been more fuel efficient to keep the aircraft longer at cruise altitude applying speed control at altitude and during descent, as required.

The impact of altitude and speed control strategies at the four airports is further exhibited by the level-flight data in table 7. In these data, the differences in strategies between MIA and LAX are clearly evident. At LAX, for example, the level-flight distance not used for path-stretching vectors was less than 8 nmi, on the average; whereas, at MIA, it was more than 19 nmi. Also the average IAS at LAX was estimated to be 208 knots, which is close to minimum clear-flap configuration speed. At MIA, the computed IAS was 242 knots, just under the FAA speed limit below 10,000 feet. The impact of the differences in operational procedures is reflected in the level-flight fuel consumption. At MIA, the average fuel consumption during level flight was computed to be 729 lb per track, while at LAX the average was 405 lb. It is felt that this difference of 324 lb per track is highly significant, particularly since the average total delay (table 3) was about the same at the two airports. It appears also that during the data collection periods of the FDDB, the LAX operations were fairly close to profile descent procedures even though these procedures were actually established by FAA at a later date.

TABLE 7. LEVEL-FLIGHT DATA

LEVEL FLIGHT DATA (PER-TRACK AVERAGES)	ORD	MIA	LAX	DCA
Level Flight Distance (nmi)	27.5	22.7	11.4	21.7
Path-Stretch (nmi)	10.7	3.6	3.5	5.2
Early Descent Distance (nmi)	16.8	19.1	7.9	16.5
Ratio of Level Distance to Track Length	42%	37%	22%	35%
Weighted Level-Flight Altitude (ft)	7,000	7,500	8,500	8,000
Track Velocity (knots)	214	271	236	244
Computed Indicated Airspeed* (knots)	193	242	208	216
Time in Level Flight (min)	7.7	5.0	2.9	5.3
Fuel Burn in Level Flight (lb)	999	729	405	375
Fuel Burn Rate (lb/nmi)	36.3	32.1	35.5	17.3

* IAS was computed from track velocity (TAS) at the weighted level flight altitude with the following equation:

$$IAS = TAS \times \frac{68320 - 0.707\ (\text{alt. in ft})}{68320 + 0.293\ (\text{alt. in ft})}$$

At ORD and DCA, the level-flight distances not needed for path-stretching vectors were about the same, on the average (16.8 and 16.5 nmi, respectively). However, there is a marked difference in the average fuel consumption during level flight (999 lb versus 375 lb), which results from (a) differences in aircraft-type distribution and (b) differences in speed control application. The effect of aircraft-type distribution is shown on figures 19 and 20. In figure 19, it can be seen that over all the FDDB samples the ratio of excess fuel consumed by the B727 to total excess fuel consumption is about the same as the percentage of B727's in the data base. At DCA, on the other hand, B727's consumed about 63 percent of the excess fuel even though this type constituted only about 38 percent of the aircraft in the sample data (figure 20).

In connection with speed control it can be seen from table 7 that, on the average, aircraft speeds at DCA (216 KIAS) were above clean-flap configuration. At ORD, however, an average IAS of 193 knots indicates that speeds requiring flaps were frequently issued by the controllers. The effect of flaps on fuel flow rate is shown on figure 16. This effect can be more clearly demonstated by comparing the fuel required to absorb 1 minute of delay through either speed control, vectoring, or holding. If the example aircraft were indicating 210 knots at 5,000 feet (276 KTAS), it would take 23 nmi for a reduction to 180 KIAS (194 KTAS) to absorb 1 minute of delay. Over this distance, 1,104 lb would be consumed at 210 KIAS, and 1,564 lb at 180 KIAS with 15° flaps; therefore, the 1-minute delay costs 460 lb of fuel by this speed reduction. Using path-stretching vectors at 210 KIAS, it would take 3.8 nmi to absorb 1 minute of delay, and the additional fuel consumption would be 182 lb. Thus, the excess fuel for the path-stretching delay is about 40 percent that of speed control when 15° flaps were required. The holding fuel flow rate for the example aircraft at 20,000 feet is about 9,520 lb/hr (table 6), or 159 lb/min. This is about 12 percent less than the path-stretching example, and 65 percent less than speed reduction to 180 KIAS. However, now consider the case where speed is reduced from 250 KIAS (269 KTAS) to 210 KIAS to absorb 1 minute of delay for the example aircraft. For these speed differences, 23.5 nmi are required to absorb 1 minute of delay. Fuel consumption over this distance is 1,128 lb at 210 KIAS and 1,010 lb at 250 KIAS; therefore, the speed control delay would cost 118 lb of fuel. One minute of path-stretching delay at 250 KIAS would cover a distance of 4.5 nmi and would require 193 lb of fuel. In this case, the delay fuel cost using speed control is about 60 percent of that using path-stretching vectors and about 75 percent of the "holding" fuel consumption (159 lb). To summarize the above, estimated fuel consumption for the example aircraft in figure 16 to absorb 1 minute delay with different ATC strategies are:

1. 118 lb--Speed reduction (250 to 210 KIAS)*
2. 159 lb--Holding at 20,000 feet
3. 182 lb--Path-stretching vectors (210 KIAS)*
4. 193 lb--Path-stretching vectors (250 KIAS)*
5. 460 lb--Speed reduction (210 to 180 KIAS)**

* No flaps
** 15° flaps

These data were based on level flight in the terminal area. It is evident that reduced speed in the descent phase (both terminal and enroute) is more efficient than any of the level-flight strategies, since the differences in fuel flow during descent are small for all operationally acceptable speeds. An example of this efficiency can be seen by comparing the data in reference 5 (DC8, 220,000 lb) for the long-range descent (0.78M/250 KIAS) with the high-speed descent (0.83 M/340 KIAS) data. From a final cruise altitude of 35,000 feet, the long-range descent requires 134 nmi and burns 1,440 lb of fuel. Starting from the same point and altitude the high-speed scenario would require 30 nmi of level flight and 104 nmi for descent. Estimated fuel consumption would be 690 lb for level flight and 1,080 lb for descent, yielding a total of 1,770 lb. From the common point, the flying time for the long-range descent is about 3 minutes more than for the high-speed descent profile. Therefore, if ETA's were based on the high-speed descent, the long-range descent profile could be used to effect 3 minutes of delay, while, at the same time, saving 330 lb of fuel. Since these data are based on the 250 KIAS FAA speed limit below 10,000 feet for both profiles, time, fuel, and distance, differences accrue prior to reaching 10,000 feet. On the assumed profile, the 10,000-foot point is 32 nmi from touchdown. The decision point for selecting the long-range descent would therefore be 102 nmi from that point and about 72 nmi from where the high-speed descent profile reaches 20,000 feet. Obviously, many factors enter into that decision, including the accuracy in estimating flying times and delay requirements. Since examination of these factors is not part of this study, the only point that can be made here is the fuel efficiency of the early descent (30 nmi, prior to high-speed profile) integrated with reduced speed. In this example, fuel was saved whether the delay was needed or not. However, early descent which causes level flight at lower altitudes is wasteful of fuel if the corresponding delay is not required.

PROCEDURAL ROUTING. As discussed in the "Method of Approach," a "minimum approach route" was constructed to correspond with each "nominal route" in order to assess the impact of local procedures on delay and excess fuel consumption. These minimum approach routes define the shortest path from the track start point to the closest runway in use (without overflying the airport), taking into account aircraft performance and instrument approach requirements. Procedural routing delay is defined as the difference in flying time over the nominal route as compared with the corresponding minimum approach route. Excess fuel consumption attributed to local procedures was derived by applying the weighted fuel flow rate in level flight to the difference in these route lengths.

As can be seen from table 3, the overall average delay attributed to local procedures was less than 1 minute per track for all airports in the data base. The average excess fuel consumption due to this delay component (table 4) was also a modest amount, varying from 67 to 115 lb per track. It is felt, however, that in this case average values are misleading insofar as providing the kind of information needed for fuel conservation methodology. It can be seen from figures 1 through 8 that many of the nominal routes provide a fairly direct path from the terminal entry point to the close-in approach pattern. In each configuration, however, there are a few cases

where the minimum approach route is substantially shorter than the corresponding nominal route. While it was not within the scope of this project to analyze the reasons for these procedural routings, it is important to identify the impact on excess fuel consumption.

Table 8 depicts excess route mileage and excess fuel consumption due to procedural routing for those nominal routes where the average nominal route mileage was 3 or more nmi longer than the average minimum approach route distance. In these data, only nominal routes with 10 or more tracks are included. At ORD, there were 26 nominal routes constructed to match the runway configurations and other conditions in the data base. Of these, only the five shown in table 8 had an average procedural routing delay greater than 3 nmi. The 186 tracks assigned to these routes (29.3 percent of the ORD sample) had an average delay of 7.3 nmi due to procedural routing, which resulted in an average excess fuel consumption of 290 lb per track. Also, these tracks accounted for 73.4 percent of the total excess fuel consumption in the ORD data that was attributed to procedural routing delay. In actuality, route 1B (PAPI to 27R) and route 7A (VAINS to 14R) together accounted for about 54 percent of the ORD procedure routing total while accommodating about 19 percent of the sample traffic (121 tracks). By inspecting these route geometries in figures 1 and 2, it appears that a considerable amount of airspace is reserved for departure traffic or other ATC purposes. Whatever the reasons may be, it would appear that a concerted effort to conserve fuel would involve a close examination of the ORD procedures with a view toward more direct routing of the heavy arrival traffic from the northeast when landing west and also from the southwest when landing to the southeast.

At MIA, 3 of the 11 nominal routes accounted for about 75 percent of the excess fuel consumption attributed to procedural routing. About 35 percent of the MIA data base tracks were assigned to these three routes. When landing west, route 1A traffic (through PINKS) was routed considerably east of the most direct route (perhaps to avoid FLL airspace), resulting in procedural delay of 7 nmi and excess fuel consumption of 258 lb, on the average. When landing west, traffic from the northwest (route 6B through NEWER proceeded to the MIA VORTAC before turning to intercept the downwind leg. This resulted in 171 lb of excess fuel for the 6 extra nmi. Also in the west configuration, traffic off of V-35 through SERPA normally vectored south of the airport to land on runway 27L. These tracks averaged 5.9 nmi more than the minimum approach route (north of the airport) and consumed 195 lb of additional fuel. It is assumed that this procedure resulted from the manner in which traffic is distributed between the "North" and "South" arrival controllers.

In the LAX data, 2 of the 12 nominal routes accounted for 89 percent of the excess fuel consumption attributed to procedural routing. The 62 tracks assigned to those routes (35.4 percent of the LAX tracks) were all from the northwest sector, whether landing west (route 5A) or landing east (route 6B). Rationale for these routings was not apparent from the data; however, noise abatement procedures and terrain problems are well known factors in the LAX area.

TABLE 8. EXCESS MILEAGE AND FUEL CONSUMPTION DUE TO PROCEDURAL ROUTING

AIRPORT-NOMINAL ROUTE	AVERAGE EFM-P PER TRK (nmi)	NO. OF SAMPLE TRACKS-"N"	NO. OF TRACKS ON NOMINAL	PERCENT OF "N" (%)	EFB-P IN SAMPLE (lb)	EFB-P ON NOMINAL (lb)	PERCENT OF SAMPLE EFB-P (%)	AVERAGE EFB-P PER TRK (lb)
ORD-		635			73,188			
1B	7.8		64	10.1		18,798	25.7	293
6B	10.4		18	2.8		5,335	7.3	296
7A	7.9		57	9.0		20,332	27.8	356
8B	5.4		25	3.9		5,149	7.0	205
8A	3.6		22	3.5		4,381	6.0	199
TOTAL	-		186	29.3		53,995	73.4	-
AVERAGE	7.3							290
MIA-		217			21,734			
1A	7.0		31	14.3		8,005	36.8	258
5B	5.9		19	8.8		3,715	17.1	195
6B	6.0		27	12.4		4,622	21.3	171
TOTAL	-		77	35.5		16,342	75.2	-
AVERAGE	6.4							212
LAX-		175			11,725			
6B	5.0		41	23.4		7,287	62.1	177
5A	3.6		21	12.0		3,147	26.8	149
TOTAL	-		62	35.4		10,434	89.0	-
AVERAGE	4.5							168
DCA-		212			15,712			
1A	3.6		32	15.1		1,930	12.3	60
1B	3.3		32	15.1		2,315	14.7	72
3B	3.6		21	9.9		833	5.1	39
4B	11.7		13	6.1		2,936	18.7	225
5A	5.0		36	17.0		4,349	27.7	120
TOTAL	-		134	63.2		12,363	78.7	-
AVERAGE	4.7							92

Legend: EFM-P - Excess miles due to procedural routing
EFB-P - Excess fuel burn due to procedural routing

The five nominal routes listed in table 8 for DCA accommodated 63.2 percent of the DCA traffic in the data base and accounted for about 79 percent of the excess fuel consumption due to procedural routing. Of particular note are routes 4B and 5A (Ironsides to runway 18 and Gilby to runway 36, respectively), where 23 percent of the DCA traffic accounted for over 45 percent of the excess fuel consumption attributed to local procedures. In both cases it appears that traffic is vectored off the most direct route to avoid the airspace used for departure traffic exiting through the Casanova VORTAC. Again, aircraft-type distribution of the DCA traffic renders a less severe impact on fuel consumption due to local procedures than at the other three airports. The fuel flow rate of these aircraft averaged just under 20 lb/nmi as opposed to 33 to 40 lb/nmi at MIA, LAX, and ORD.

FACTORS CONTRIBUTING TO DELAY AND EXCESS FUEL CONSUMPTION.

GENERAL. From the previous discussion, it is evident that no single formula fits the four airports in the data base relative to delay and excess fuel consumption. This can be seen more clearly by reference to figure 21, where excess fuel attributed to the four delay components is presented for each airport as a percentage of the total excess fuel consumption derived for all tracks in the data base. It is fairly obvious that the ORD data in figure 21 are indicative of the persistently heavy traffic demand at that airport. For example, in the total FDDB, the ORD samples accounted for 51 percent of the tracks, while the other three airports together produced the other 49 percent. Also, the excess fuel consumption derived for the ORD portion of the tracks amounted to 73 percent of the total for the entire data base. It can be inferred, from the excess fuel attributed to each component of delay (excluding procedural routing), that demand exceeded capacity throughout most of the sample from ORD, while such was not the case at MIA, LAX, and DCA. The one apparent incongruity to this inference is the ratio of the early descent/speed control data depicted for MIA. However, as explained earlier, the MIA tracks were generally descended early, but very little speed control was exercised. Although it cannot be proven with certainty from the data, it appears that the practice of descending aircraft early at MIA resulted in unintentional delay and unperceived excess fuel consumption. Note, however, that these data were collected before profile descent procedures were implemented. Such procedures should minimize results of this type.

In the LAX data, the converse of MIA seems evident. Generally, the LAX tracks conformed to a fuel-efficient profile when delay was not required. In this regard, however, the author has some reservation with respect to how nearly the sample data reflect true demand at either LAX or MIA. Although not apparent from figure 21, the excess fuel consumption data at DCA were strongly influenced by aircraft-type distribution and the requirement for landing slot reservations. In addition, the FDDB data collected from DCA were recorded during good VFR weather conditions, and frequently arrivals were assigned to a secondary runway. During IFR conditions, a single arrival runway is used at DCA. It is expected that such conditions would produce substantially different results for DCA than those derived from the FDDB.

In order to identify the effects of weather, runway configuration, and other factors on excess fuel consumption, it is necessary to apply different sampling criteria than those used for the ATC/ACAS study. However, in an attempt to extract as much information as possible from the available FDDB collected for that study, it was decided to organize the ORD data into the various groupings as shown in figures 22 through 25 for comparison purposes. These data are discussed in the subsequent sections.

EFFECT OF WEATHER. In the ORD sample, 3 data hours were collected during IFR weather when the parallel 14L/14R runway configuration was in use, and 3 hours were collected during VFR conditions with the same runway configuration. Figure 22 depicts average delay time and excess fuel consumption per track for these two conditions. In these data, delay during IFR exceeded delay during VFR by 19 percent (12.3 versus 10.3 min), and excess fuel consumption in the IFR data was 26 percent greater than in the VFR data (1,415 versus 1,118 lb per track). Although, these results may appear to be as expected, there was considerable variation among the sample hours as shown in figure 23. Note, for example, the holding data from example I_1, as compared to samples I_2 and I_3, and in sample V_1 as compared to V_2 and V_3. Also note that the average vector delay in sample V_3 (14.7 nmi) was almost twice that in sample V_2 (7.9 nmi). These differences do not seem to correlate with the landing rates shown at the top of figure 23, nor can they be explained from other aspects of the ORD data base. Evidently, such differences are a result of other factors, such as short-term demand, controller strategy, differing center/tower procedures, etc., which require more information to isolate than was available in the FDDB.

EFFECT OF RUNWAY CONFIGURATION. From discussions with ORD personnel, it was found that the 32L/27R, or "dual," configuration was considered to be the most efficient runway configuration for arrival aircraft (departures use 32R/27L). This seems to be confirmed by the sample data on figure 22, where delay with the dual configuration (7.7 min) was about 25 percent less than the average delay with the parallel, 14L/14R configuration (10.3 min) where both operations were during VFR weather. However, as shown on figure 23, inconsistencies between the dual-sample data also exist. Note the average delay mileage in the D_2 sample (22.7 nmi) as compared with 6.6 and 8.8 nmi in D_1 and D_3, respectively. Also, the average delay in the V_2 sample (8.5 nmi) is about the same as the better dual samples. Again, the reasons for such variation between samples were not detectable from available data.

EFFECT OF APPROACH PATTERN GEOMETRY. (Note: Programing support for the project was canceled before it was decided to analyze delay and excess fuel consumption due to early descent and speed control. Consequently, these data could not be extracted for all data groupings, such as those shown in figures 24 and 25).

Nominal route geometry was classified as being either a straight-in, a base leg, or a trombone (downwing/base leg) pattern. These geometries provide differing degrees of controllability and therefore require different control strategies to produce the required spacing in the arrival sequence. Accordingly,

it is of interest to determine the results of such strategies on delay and excess fuel consumption.

As shown in figure 24, aircraft that flew a trombone pattern (most controllability) had the most delay (25.5 nmi), while the straight-ins (least controllability) had the least delay (12.6 nmi). Average delay for tracks on a base leg pattern (23.0 nmi) also seems to correlate with controllability; i.e., slightly less than trombone and substantially more than straight-in. This relationship between delay and controllability is a more or less natural characteristic of a radar (ATC) environment, where, generally, "the end justifies the means." It is unfortunate, however, that speed control data were not available for these comparisons, since aircraft on a straight-in are more likely to be given lower speeds than aircraft on the other patterns. As shown earlier, speeds requiring flaps have a pronounced effect on fuel consumption relative to the amount of delay absorbed. Also, the matter of "holding" by ARTCC should be considered. Feeder (holding) fixes on a straight-in pattern are normally closer to the final approach gate than the feeder fixes on base leg and trombone patterns. This may very well influence the decision by the center to put aircraft in a holding pattern, and, when held, the shorter distance could affect the handoff time from ARTCC relative to other arrivals. Whether or not this is true could not be ascertained from the FDDB, since ARTCC holding data were not available.

EFFECT OF ENTRY SECTOR. The data on figure 25 were organized in order to see if a relationship exists between excess fuel consumption and terminal entry sector. From the 12 sample hours at ORD, there does appear to be a definite relationship between these factors. Note that the average excess fuel consumption for the 193 tracks through the southeast (SE) sector was about half that for the 135 tracks through the southwest (SW) sector. Part of this difference can be attributed to the percentage of straight-ins from the SE (43 percent) versus a nearly equal ratio (51 percent) of base leg patterns from the SW.

More noticeable, however, in the differences in holding data (321 versus 48 lb) and in procedural routing (215 versus 40 lb). Actually, "holding" and procedural routing combine to account for most of the differences between all entry sectors. From visual inspection of arrival and departure tracks in the ORD data, it appears that the small amount of procedural delay in the SE sector, as compared to other sectors, is a direct result of the way the airspace is segregated between arrivals and departures. However, there is no explanation from the data regarding the reduced amount of holding in the SE sector. Possibly because the traffic flow is somewhat heavier, there may be a different arrangement between approach control and the terminal sector in the ARTCC.

OTHER FACTORS AND CONSIDERATIONS. Undoubtedly there are numerous other factors that should be considered relative to excess fuel consumption. Furthermore, most factors are closely interrelated. However, to identify all factors, and their interrelationship would require a data collection and analysis effort far beyond the scope of this project. It is felt, however, that the discussion in this section, together with the discussion in the

previous section, should impart pertinent information relative to the consumption of excess fuel in terminal areas. These data were reduced from real-world tracks with the only motivation being to extract and disseminate maximum knowledge relative to this most important problem.

DESCRIPTION OF METHODOLOGY

GENERAL.

It was pointed out in the "Method of Approach" section that data recorded by ARTS require a considerable amount of processing and editing before being effectively applied to operational analyses. It was found that in order to derive credible delay data from ARTS tracks it is necessary to provide for manual intervention at various points in the process. Figure 26 depicts a simplified block diagram of the methodology developed to derive delay and excess fuel consumption in the terminal area. Subsequent sections briefly describe each functional block.

Before proceeding with a description of the process, it should be pointed out that the cornerstone of the approach taken was the use of nominal routes against which track data were compared. While other methods for deriving delay, such as a relative frequency distribution of flying times, could have been applied, it was felt that a direct, one-to-one comparison of track versus nominal route yielded the most accurate and complete information regarding path-stretching delay, controller strategy, procedures, and other factors.

It can be seen from figure 26 that a considerable amount of work preceded the development of nominal routes. On the surface, this may appear overdone. As it turns out, however, very small deviations can cause substantial differences in the final results, particularly when dealing with high-density terminal area traffic.

TRACK DATA BASE PREPARATION.

For the most part, the data-recording capability was established at selected ARTS facilities to monitor system performance and assist in maintenance and modification needs. The data tapes are retained for a 15-day period for legal purposes and following that period may normally be obtained from the facility, provided appropriate coordination and administrative procedures are followed. However, since the recording of ARTS data are not directed towards analysis of the ATC system, considerable effort is required in the selection and preparation of data elements needed to meet specific analytical objectives. Figure 27 depicts an overview of the data preparation steps followed during the ATC/ACAS Interaction Study which resulted in the FDDB used in this delay and fuel consumption analysis. A detailed discription of the software and other data preparation activities may be found in reference 3 and associated program documentation. Although this data preparation process was designed specifically for the ATC/ACAS work, it is probably

representative of the effort required to prepare field data for most analytical applications. Accordingly, a brief description of the principal program functions follows.

CONV 79 (Block 1.1). This is a straightforward conversion of data on seven-track ARTS tapes to nine-track tapes compatible with the National Aviation Facility Experimental Center (NAFEC) computers.

TLP (Block 1.2). This "Track Listing Program" performs the following functions:

a. Selects tracks for a specified sample hour from the source data.

b. Converts the ARTS position coordinates to a coordinate system common to all locations in the FDDB.

c. Provides a listing of tracks in the sample hour together with data describing the quality of each track.

d. Produces an output tape containing selected elements of information needed for succeding steps.

DATSYN (Block 1.3). This program has two primary functions:

a. Adds altitude information to tracks which do not have mode C transponder data. On the ATC/ACAS project, altitude data were taken from pilot/controller voice tapes and encoded for input to computer program DATSYN.

b. Performs editing of track data to eliminate anomalies and spurious data which can normally be expected in field-derived data. Some of the abnormalities can be screened by program logic, while others require manual inspection and evaluation of the track data. For example, in the ATC/ACAS project an altitude change rate criterion was used wherein the program could detect most of the spurious altitude data. On the other hand, gaps in the track positional data required manual evaluation and input editing commands for the program to make the necessary track modifications.

DATA TRANSLATION PROGRAM (DTP) (BLOCK 1.4). The primary functions of this program are:

a. Performs parabolic (nine-point) smoothing of track position and altitude which renders the data more suitable for fine-grain analysis than results from the ARTS alpha-beta smoothing algorithm.

b. Performs between-point interpolation to produce track data points at 1-second intervals. This was necessary for the ATC/ACAS project, since ACAS logic was predicated on a 3-second cycle time; whereas, ARTS data are acquired at approximately 4-second intervals (antenna rotation rate of 15 revolutions per minute (rpm)).

c. Produces an output tape of smoothed, 1-second "snapshot" data of all tracks in the system. It was the set of DTP output tapes that provided the data source for this study.

TRACK SIMPLIFICATION AND PLOTTING.

At the outset, it was apparent that plots of the arrival tracks would be required in the development of nominal routes and, later on, in associating individual tracks with the appropriate nominal routes for path-stretching computation. In the interest of efficiency in plotting and other processing, it was desirable to (a) reformat DTP data from interleaved scan form to chronological track history form and (b) reduce the number of data points that defined each track. The programs shown on figure 28 were developed to reformat, simplify, and provide visual presentation of the FDDB tracks.

HALFTRACK (Block 2.1). Due to the age of the DTP tapes, numerous read errors occurred. Also, for some locations, a sample hour required two DTP tapes. The HALFTRACK Program was written to copy the DTP data onto one tape by eliminating odd-second data points. Also most read errors were eliminated.

TRACKS (Block 2.2). This program converts interleaved scan data into a chronological track history format. The choice of formats depends upon project requirements. The ATC/ACAS project was interested in the instantaneous relationship of one aircraft to another; whereas, this project needed entire track histories for delay and fuel computations.

SIMTRACK (Block 2.3). This program performs the following range of functions to facilitate manual and computer-based analysis of track data:

a. Eliminates overflight tracks from the data base.

b. Eliminates arrival and departure tracks with track durations less than specified values.

c. Detects and flags data gaps and computes an estimate of distance flown during the gap in the track data.

d. Reduces the number of data points in the track history by redefining straight-line segments with intervals of 30 seconds (parameter) between data points. A linear regression technique was used to determine straight-line track segments. When the error sum of squares value exceeded a specified value, the track was assumed to be turning. When this occurs intervals of 4-second spacing are retained in the track history.

e. SIMTRACK also computes an estimate of the aircraft's final track heading and velocity. Normally, these data have little meaning for departures; however, for arrivals the data can be used to determine landing runway, an estimate of landing time, and other uses depending upon project requirements.

AREAPLOT (Block 2.4). The plotting program developed for the project was designed to satisfy a wide range of requirements. This includes plotting combinations of routes, fixes, runways, track histories, and other data. In view of the magnitude of the data base and the fact that all tracks had to be plotted one or more times, the program was designed so that a complete tape of track histories could be plotted in a single operation of the program. This

is accomplished by fitting six, 20 x 20 inch x, y grids into the basic CALCOMP grid and plotting up to eight (option) tracks on each grid. When data for the six grids have been plotted, the program stops, allowing the operator to position new paper on the plotter bed and then restart the program. This continues until all tracks on the tape have been plotted. Some of the more important options of the AREAPLOT program are:

a. Information to be plotted, i.e., arrival tracks, departure tracks, nominal routes, reference fixes, boundary circle, etc. Also, tracks to be plotted may be selected by aircraft identification or, if not selected, all tracks on the tape will be plotted, with an option of up to eight tracks on each x, y grid.

b. Plotting scale - 6 nautical miles (nmi) per inch was used in this project.

c. Color coding - i.e., routes and background data of one color and three tracks each of a different color enhanced the readability for this project.

d. Fix identification may or may not be plotted, as desired. If plotted, the height of the fix identification (ID) lettering can be controlled separately from other lettering.

e. Real time associated with track position may be plotted with control over height of the plotted numbers.

f. The center and radius of a boundary circle can be controlled. For this terminal area work, a circle with 55-nmi radius centered at the primary airport was used.

g. Compass roses, strategically located at various points on the grid, may be plotted to the desired size. This facilitates the measurement of bearing data.

From the list of user options, it is obvious the AREAPLOT program provided a key interface between the analyst and the computer. As will be seen, this program box will appear as an integral part of most of the steps in the methodology developed for the project. Its description at this point is for continuity purposes only.

AIRWAY DATA BASE PREPARATION.

As shown on figure 26, the preparation of airway data and terminal area geometry can be performed in parallel with the preparation of track data, leading up to the development of nominal routes. In a general sense, the purpose of the system of programs depicted on figure 29 is (a) to establish readily usable disk files of real world data which are available from different sources, and (b) to provide a convenient method to extract data needed for specific project requirements.

Through use of this system, three interrelated files are created on the Sigma 8 disk pack for ready access. The programs which process the FAA Airport Master tapes (blocks 3.1, 3.2, and 3.3) produce an alphabetized file of airports with three-letter identification where all extraneous (i.e., administrative) data have been removed. Also, three programs (blocks 3.4, 3.5, and 3.6) are used to provide a similar file of navigation aid (NAVAID) data from the FAA NAVAID Master tape. The EXPER program (block 3.7) creates a file of airway, route, and associated fix data from the Controllers Chart Supplement Subscriber tape established and maintained by National Ocean Survey, National Oceanographic Atmospheric Administration (NOAA). The AIREDIT program (block 3.12) provides the capability to enter manual corrections to the airway/route file, based on the diagnostics provided by the EXPER program. Manual corrections to the airway/route data base are made on the tape input to AIREDIT through use of the TRANSFORM 3 program (block 3.10) together with the AIRWAY 3 program (block 3.9). AIRPULL (block 3.8) is an extractor program which selects, from the disk files, airway and route data contained within a specified lat/long box of up to eight sides (convex polygon). The OMNIPLOT program (block 3.11) plots, under a wide range of options, the airway/route data selected by AIRPULL.

Several of the programs shown on figure 29 (asterisked) were developed during a previous area navigation high-altitude network study. Detailed descriptioning these programs are contained in reference 4. In particular, programs TRANSFORM 3 and AIRWAY 3 are network design oriented where route or airway design is primarily a manual function. Through the use of simple command codes, design decisions can be transformed into an airway/route structure data base which is amenable to further computer processing required for effective network design. Further, these programs together with AREAPLOT provided the essential software used in this project for nominal route development.

TERMINAL AREA GEOMETRY EXTRACTION.

Once the airway/route data have been stored on disk files, the software shown on figure 30 can then be used to select and plot data for the particular terminal area of interest. In this project, the selected data provided the starting point for nominal route development, discussed in the next section. The CALCOMP plots served as initial worksheets where the plotted data could be cross-referenced with preferred route descriptions, prestored flight plan data, operating manuals, letters of agreement, etc. The programs shown on figure 30 were briefly discussed in previous sections of this report.

NOMINAL ROUTE DEVELOPMENT.

As discussed in the "Method of Approach" section, nominal routes were developed in order to derive estimates of path-stretching delay. A schematic of the steps taken in the development process is presented in figure 31. The programs shown on figure 31 have been discussed in earlier sections and the ground rules and procedures used in constructing nominal routes were presented in the "Method of Approach."

From previous RNAV work, it was recognized that development of route structures is a highly judgmental process which can only be automated to a limited degree. Therefore, as can be seen from figure 31, nominal route development was centered around a manual design effort, assisted, to the extent practicable, by computer techniques. The development effort proceeded in an iterative fashion so that configurations could be checked against representative track data and modified as necessary. This process has broad applications for studies dealing with terminal area traffic control.

ASSOCIATION OF TRACKS WITH NOMINAL ROUTES.

Following the development of nominal routes, the next step in the process was to associate each track with the appropriate nominal route for subsequent path-stretching delay computation. This step is depicted in figure 32. Although program logic could have been developed which would make the correct association most of the time, considerable manual review would still be required due to the many vagaries in the track data. Therefore, it was decided to leave track association as a manual function. In addition to associating tracks with nominal routes, other additions and/or changes to the track history data base were required. Manually derived data were encoded for input to the TRAMP program which interpreted the command functions and made the appropriate additions and changes to the data base. The following input commands were used in this project.

ASSIGN TRACK (AT). With this command, the program stored the assigned nominal route in the track file and automatically put in runway coordinates as the last track position (for arrivals).

DELETE TRACK (DT). If the track was considered inadequate for mileage computation, the DT command was used. Track data were not deleted from the file with the DT command; however, a flag was set indicating that the track was not to be included in mileage computation. Holding data, on the other hand, could be retained and processed for deleted tracks (see "HOLD," below).

CHANGE STATUS (CS). For various reasons the "arrival, departure, overflight" status code was sometimes in error in the ARTS data. When the error was detected from the plotted track, the CS command was used to correct the data base.

HOLD. This command was used to input "start" and "end" holding times as observed on the track plot. The program computed estimated distance flown during these times and stored holding times, distance flown, and holding altitudes in the data base. Track histories were also modified so that holding distances were not included in track mileage, since holding data were treated as a separate delay component. Holding data were retained for deleted tracks as well as for tracks associated with a nominal route. In this way, hourly holding data could be tabulated for the terminal area.

MODIFY TRACK (MT). Due to the fact that the FDDB samples were 1-hour slices in time from the ARTS recorded data, track data at the beginning and at the end of each sample were frequently of insufficient duration for delay analysis.

In lieu of deleting all incomplete tracks, however, it was found that many tracks could be salvaged through additions and/or slight modifications to the track history. In this process, the overriding consideration was not to impose bias in track distance. If this could not be done, then the track would be deleted from the mileage computation. In addition to incomplete tracks, there were other reasons why track history data required modification. As mentioned earlier, holding data needed to be extracted. Also, on occasion, the plots would show that the aircraft landed on a different runway than the one in the corresponding nominal route. To avoid bias in the distance computation, it was necessary to replace the runway of the nominal route with the actual runway. Bias could also be introduced if the beginning portion of the track was too far from the nominal. This section of the track could easily be truncated by use of the MT command.

Several input commands for TRAMP were programed to aid in the modification process. These commands, used in conjunction with the MT command, were as follows:

a. New Fix (NF). This command established an identifiable position which can subsequently be used to insert, through MT, additional points in the track history in order to make an incomplete track usable for mileage computation. This method of track modification was only used if it could be judged from the available track data that the actual track would have had to pass in close proximity to the added points. A good example of this application was where the last few data points of the track history indicated that the aircraft had made the turn onto base leg just before the end of the sample hour. In all probability, a normal approach with no further path-stretching was made from that point on. By adding one or more track "fixes," track mileage could be computed without bias.

b. Take Nominal From (Fix) to (Fix). Another way of inserting positional data in track history was to use portions of the assigned nominal route as track position data. Again, precautions were taken with the use of this command, so as not to introduce bias in the track length computation.

c. Take To, From, or From/To (Times). With these three separate commands, track histories could be modified through use of the real time data associated with track position. Generally these commands were used for extracting holding data or to remove positional data at the beginning of a track which would cause bias in mileage comparisons.

The inputs to the TRAMP program were encoded in free format which generally resembled a high-order computer language. Diagnostics were provided to detect input errors, and plots of the associated track histories were made for manual review. Corrections were encoded and processed in the same manner as the original data.

ROUTE MILEAGE AND DELAY COMPUTATION.

At the completion of the track association function, a data base of usable tracks was available for route mileage and delay computation (block 7.0, figure 26). As shown on figure 33, this function consists of two computer programs (NOMLEN and TRKDAT), plus some manual work which was added during the analysis phase of the project. The rationale for manually derived early descent and speed control data (block 7.3) was discussed in the "Method of Approach" section.

The NOMLEN program (block 7.1) computed route lengths for nominal and minimum approach routes which served as an input to the TRKDAT program. In this computation, adjustments were made at each turn in the route to account for aircraft turn radius.

The TRKDAT program performed a range of functions necessary to derive delay due to path-stretching, holding, local procedures, early descent, and speed control. The principal functions of TRKDAT are embodied in the discussion of these delay components in the "Method of Approach" section.

EXCESS FUEL COMPUTATION AND DATA SUMMARY.

The final step in the process to derive estimates of excess fuel consumption in the terminal area from ARTS tracks is shown on figure 34. This process consists of the FUELBURN program, which computed excess fuel consumption due to excess mileage and holding, and the SUMMARY 3 program, which provided a wide range of higher order summaries of these data. In addition, a manual effort was added during the analysis phase of the project to derive an estimate of excess fuel consumption due to early descent. Details of excess fuel computation are presented in the "Method of Approach" section.

As shown on figure 34, the SUMMARY 3 program provides the capability to produce higher level summaries in accordance with a range of input options. These higher level summaries for the ORD data in the FDDB are included as an appendix to this report.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study, it is concluded that:

1. Analysis of ARTS track data is an effective method to derive credible estimates of terminal area delay and excess fuel consumption. However, delay to arrivals may start to accrue while aircraft are still under center control. Therefore, for more complete analysis of terminal area delay, data should also be collected from appropriate sectors of the ARTCC.

2. To avoid misleading results, the process used to derive delay estimates from track data should provide for manual intervention at appropriate points. This follows from the fact that the recorded data are characterized by anomalies, spurious data, and other vagaries.

3. The need for fuel-efficient, delay-absorbing techniques is clearly evident from the delay and excess fuel consumption data derived in this project for the Chicago O'Hare (ORD) airport. From these data, it was estimated that annual delay costs to ORD arrivals is in the range of 33 to 40 million dollars. Although ORD represents a "worst case" situation at the present time, delay at other major hubs is rapidly increasing due to the accelerating traffic growth.

4. Rigid procedures that absorb all terminal area delay in high-altitude holding stacks do not provide the most fuel-efficient way to absorb delay. Fuel-efficient scenarious to absorb delay should include appropriate combinations of the following strategies, which are listed in descending order of fuel efficiency:

   a. Reduced speed while descending from enroute altitude to metering fix altitude,

   b. Reduced speed at enroute cruising altitude,

   c. Descent to an appropriate lower cruising altitude to effect further speed reduction,

   d. Reduced speed between the metering fix and the approach gate, but not to speeds requiring flaps,

   e. High-altitude holding,

   f. Path-stretching vectors, and

   g. Lower speeds near the approach gate for fine-grain control.

From the conclusions, it is recommended that:

1. The methodology developed for this project be expanded and/or modified, as necessary, to provide a general purpose capability for the analysis of terminal area operations from the data being recorded by ARTS.

2. Procedures and techniques be developed which incorporate the delay-absorbing strategies listed in conclusion number 4.

3. A data collection program be established to measure the efficiencies of the delay-absorbing strategies after implementation.

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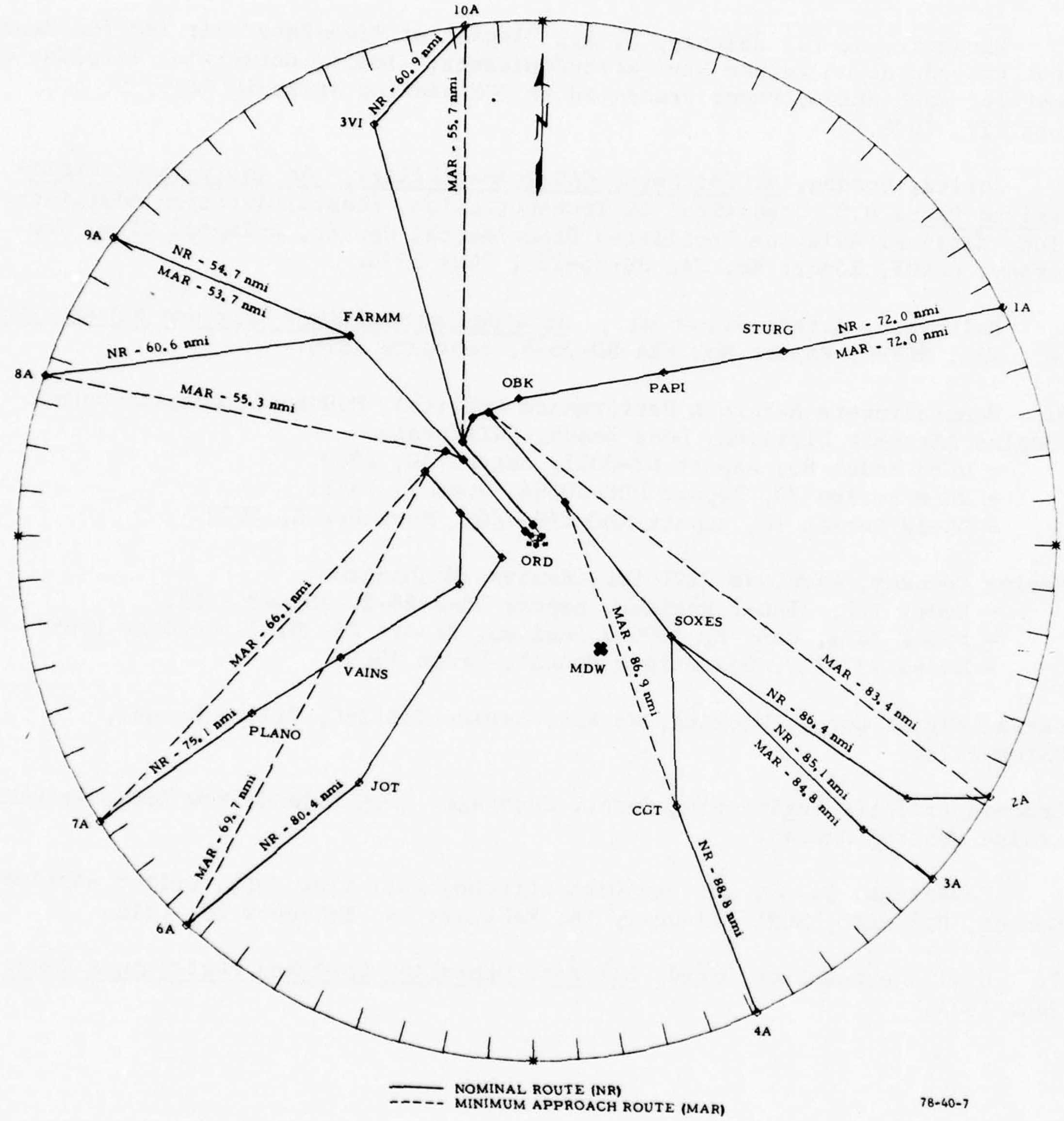


FIGURE 1. NOMINAL ROUTES--ORD CONFIGURATION A (PARALLEL OPERATIONS--RUNWAYS 14L/14R)

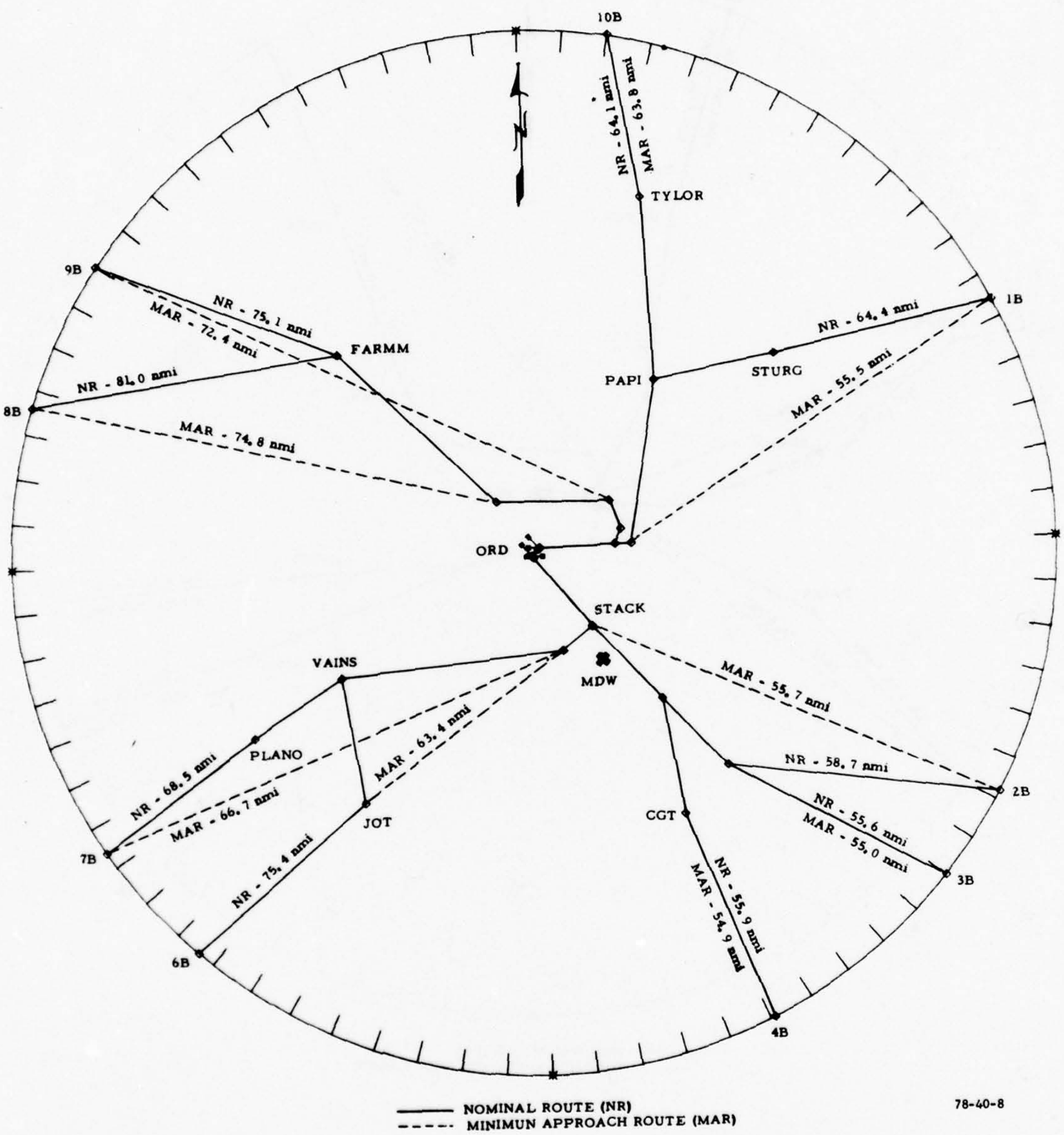


FIGURE 2. NOMINAL ROUTES--ORD CONFIGURATION B (DUAL OPERATIONS--RUNWAYS 32L/27R)

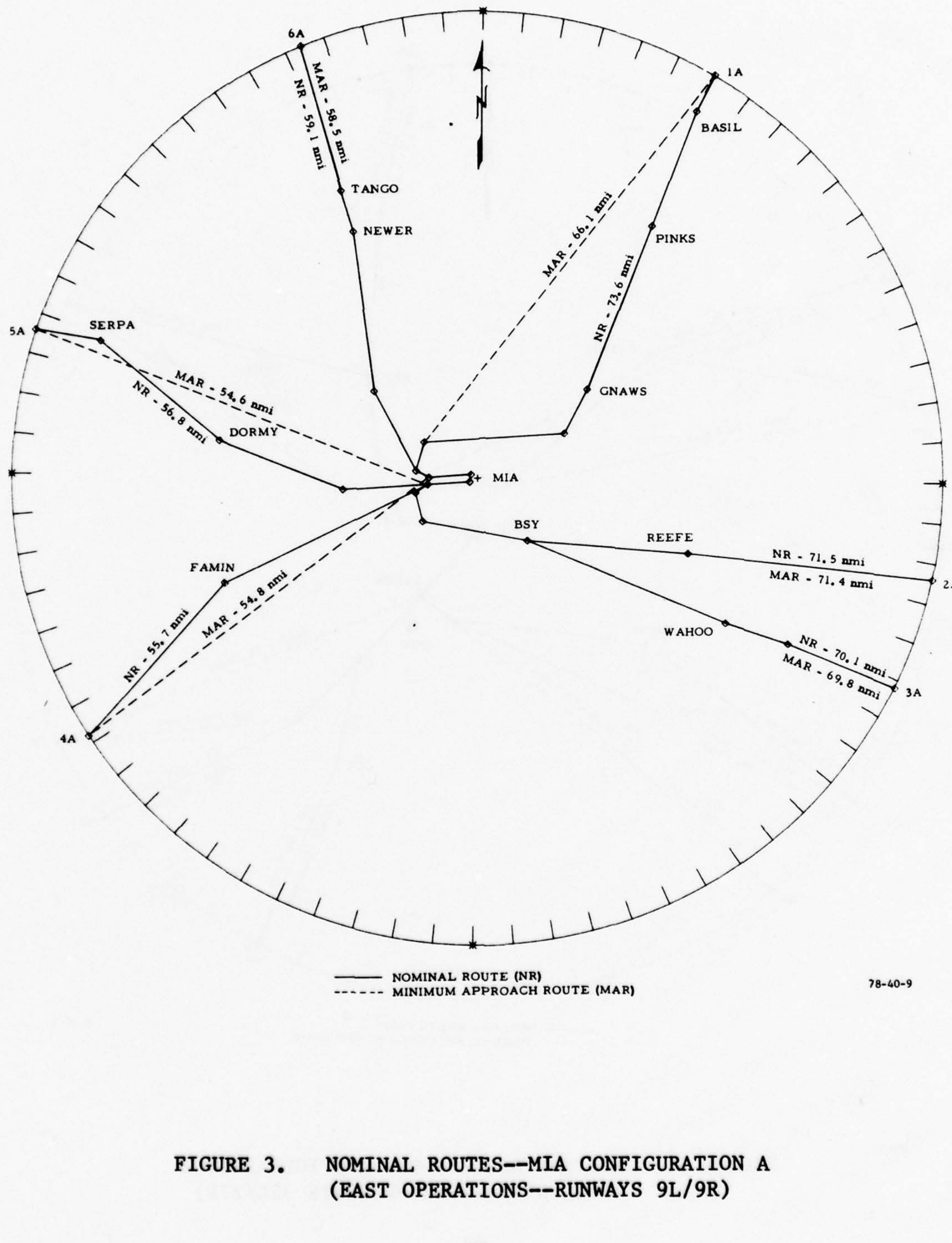


FIGURE 3. NOMINAL ROUTES--MIA CONFIGURATION A
(EAST OPERATIONS--RUNWAYS 9L/9R)

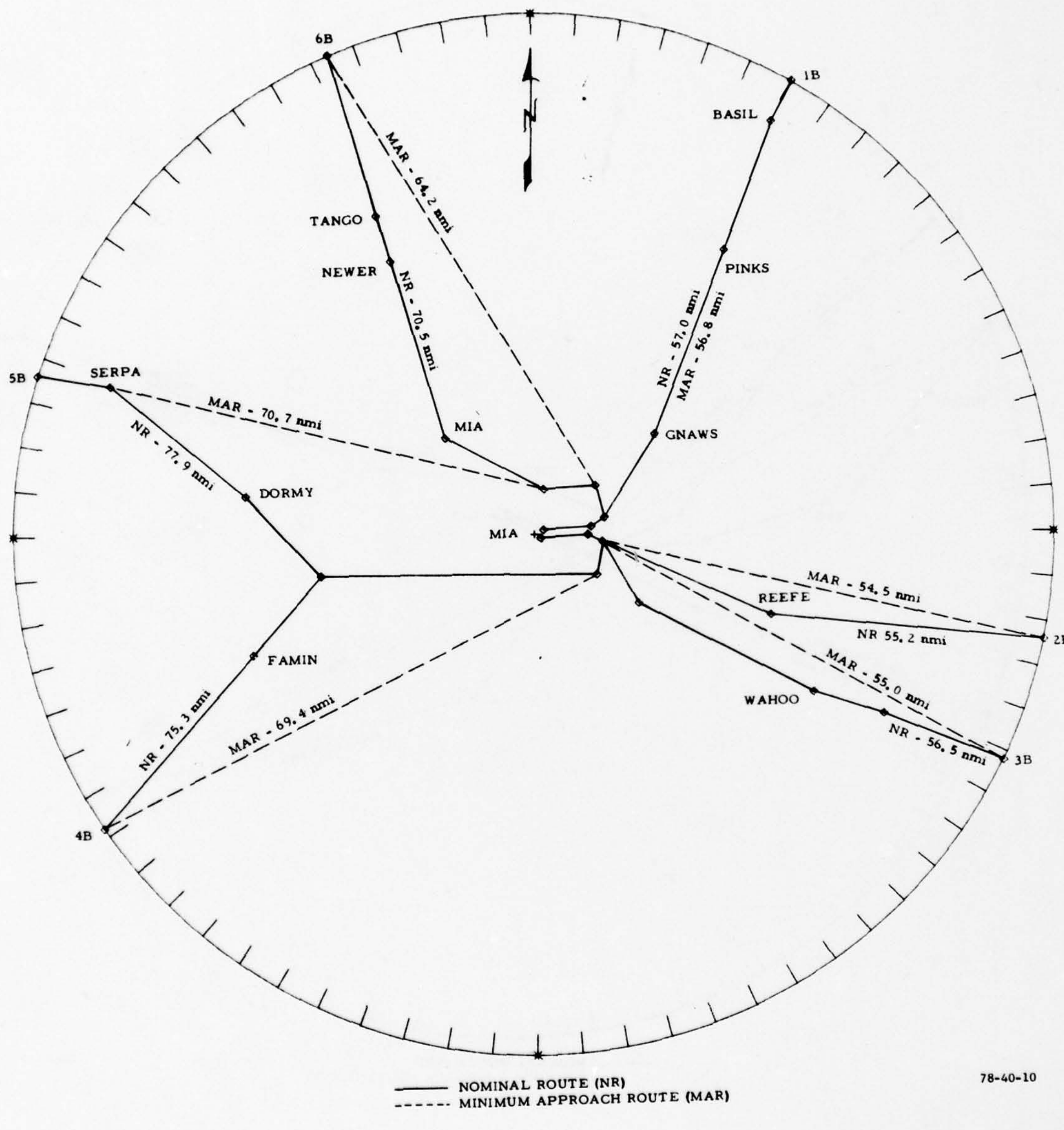


FIGURE 4. NOMINAL ROUTES--MIA CONFIGURATION B
(WEST OPERATIONS--RUNWAYS 27L/27R)

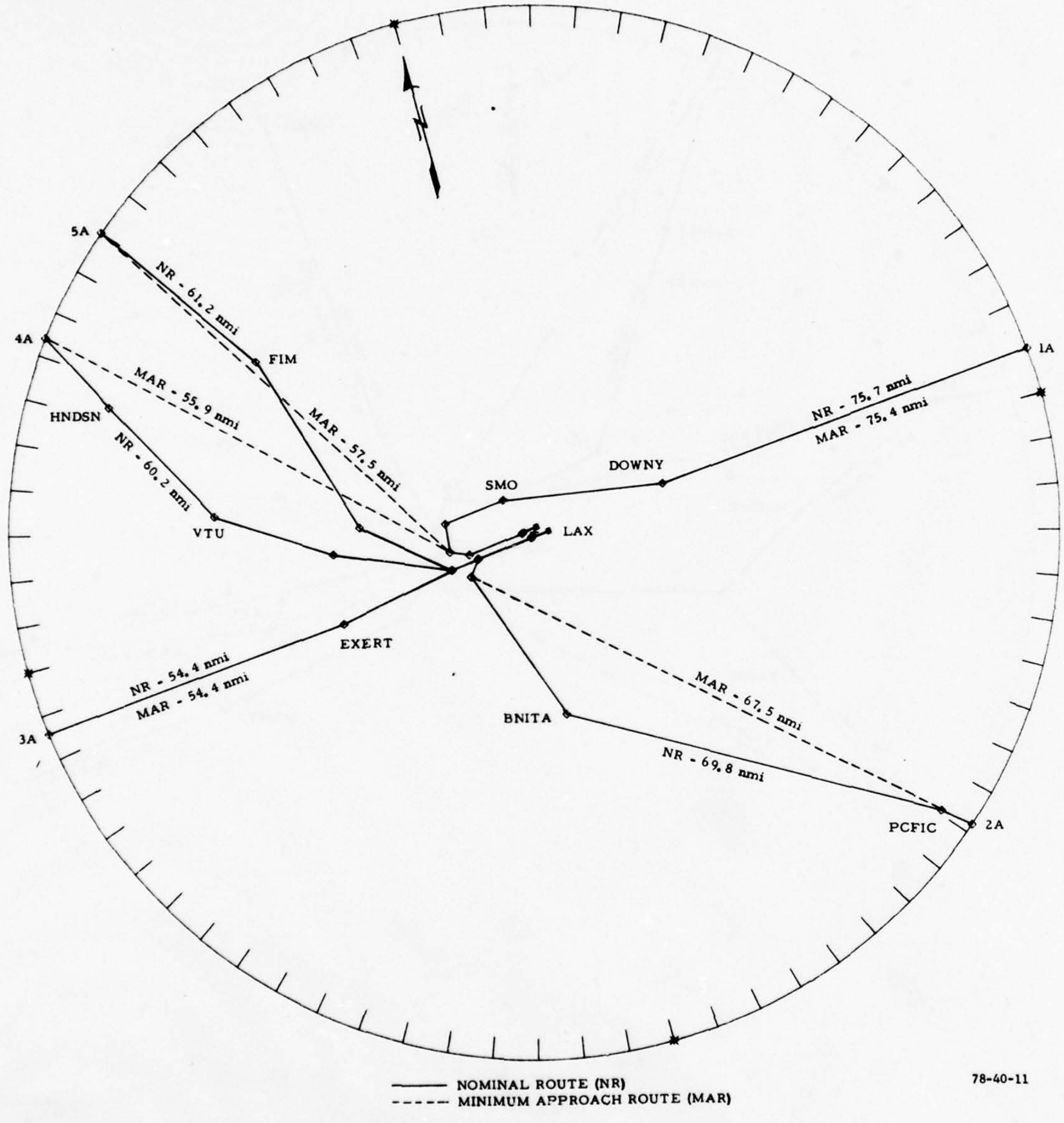


FIGURE 5. NOMINAL ROUTES--LAX CONFIGURATION A
(EAST OPERATIONS--RUNWAYS 6/7)

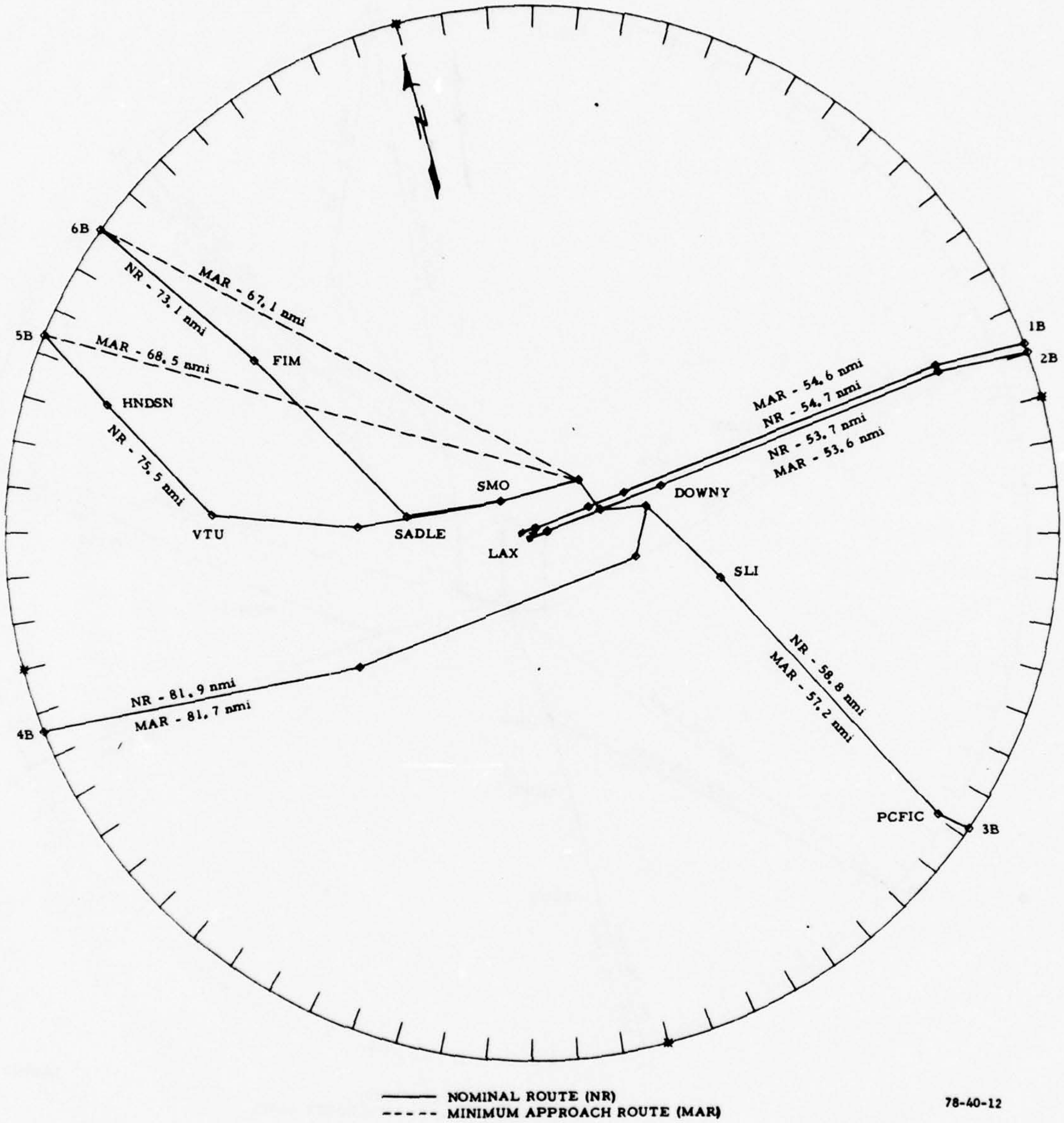


FIGURE 6. NOMINAL ROUTES--LAX CONFIGURATION B (WEST OPERATIONS--RUNWAYS 24/25)

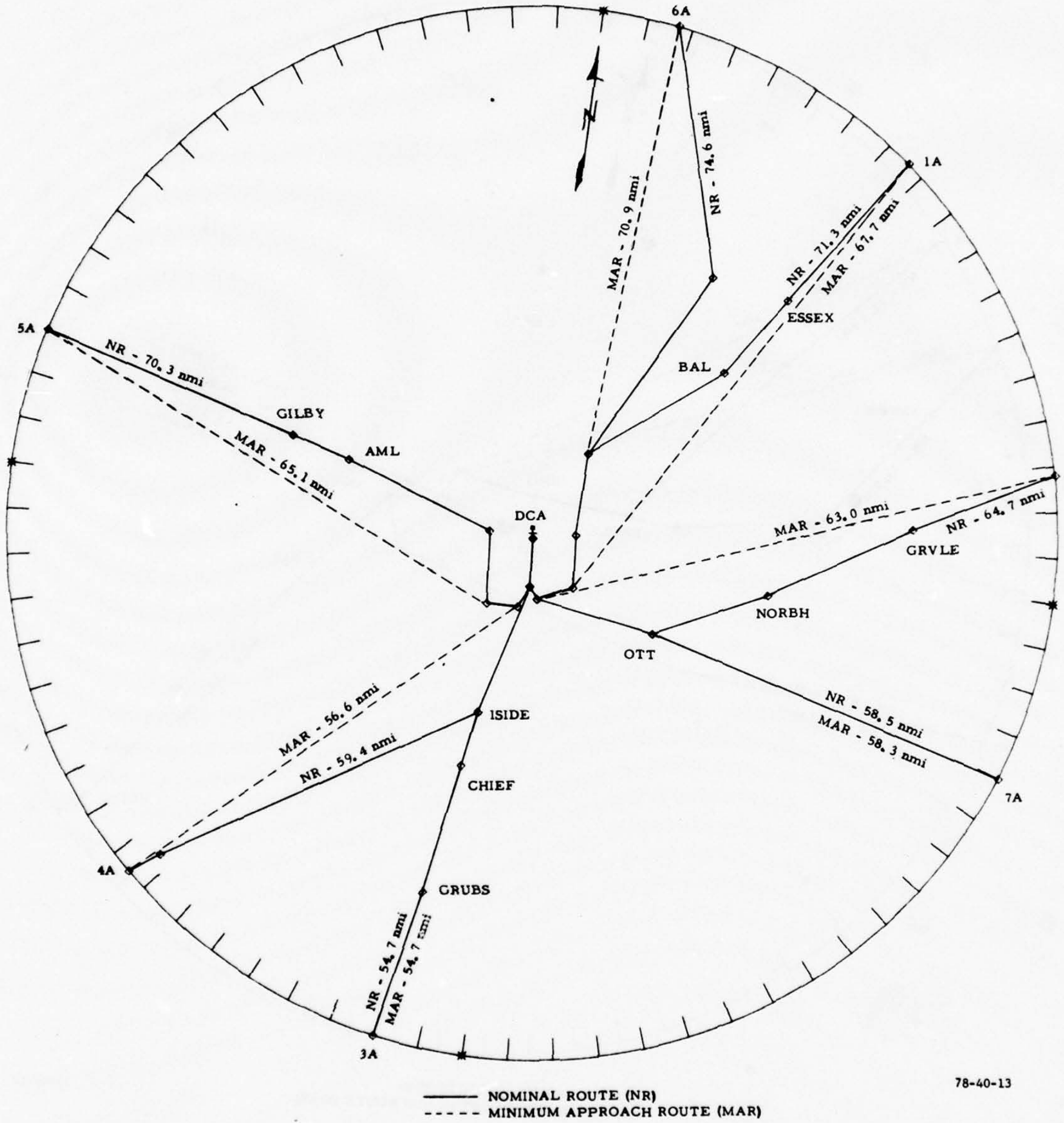


FIGURE 7. NOMINAL ROUTES--DCA CONFIGURATION A (NORTH OPERATIONS--RUNWAY 36)

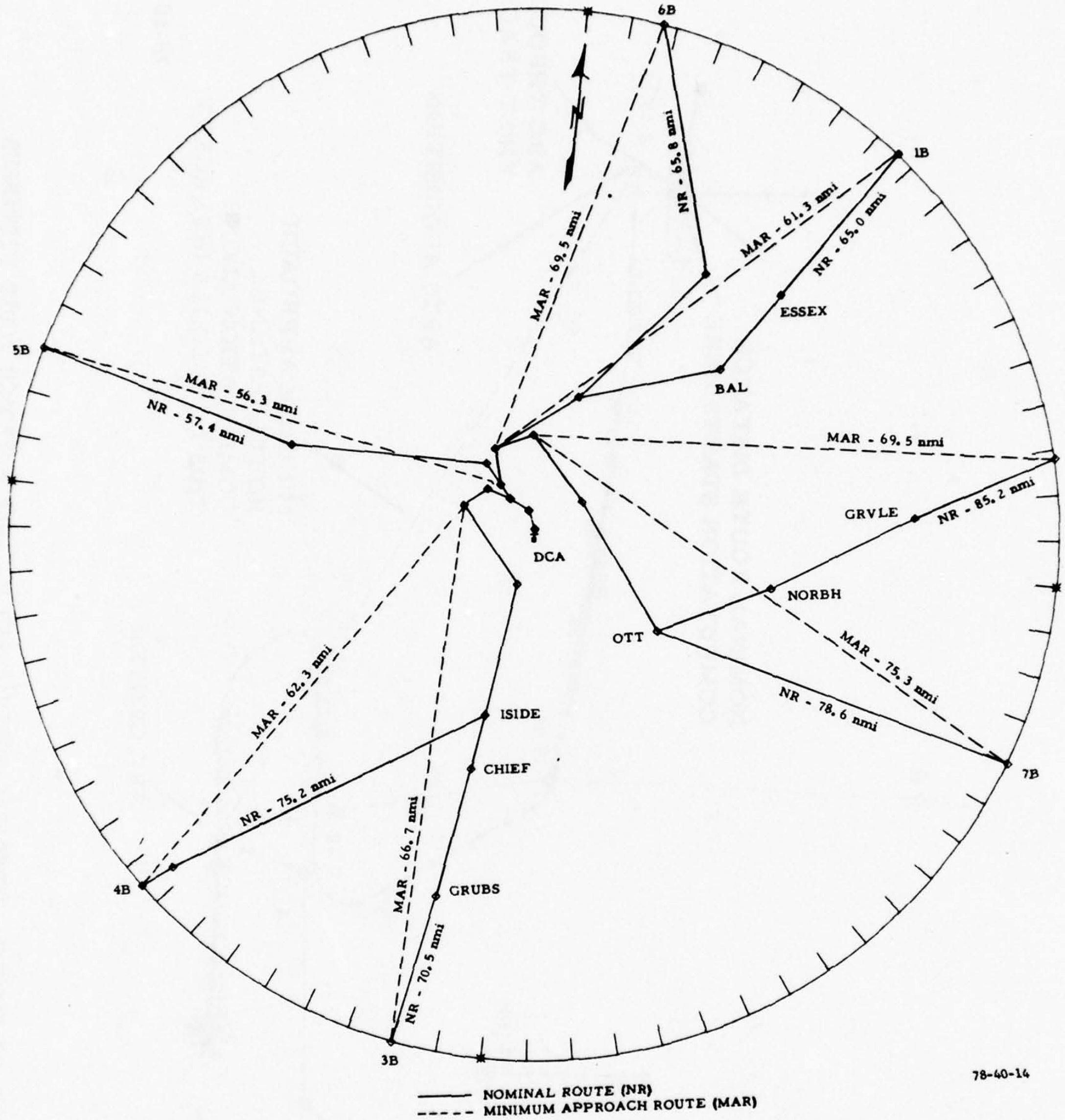


FIGURE 8. NOMINAL ROUTES--DCA CONFIGURATION B (SOUTH OPERATIONS--RUNWAY 18)

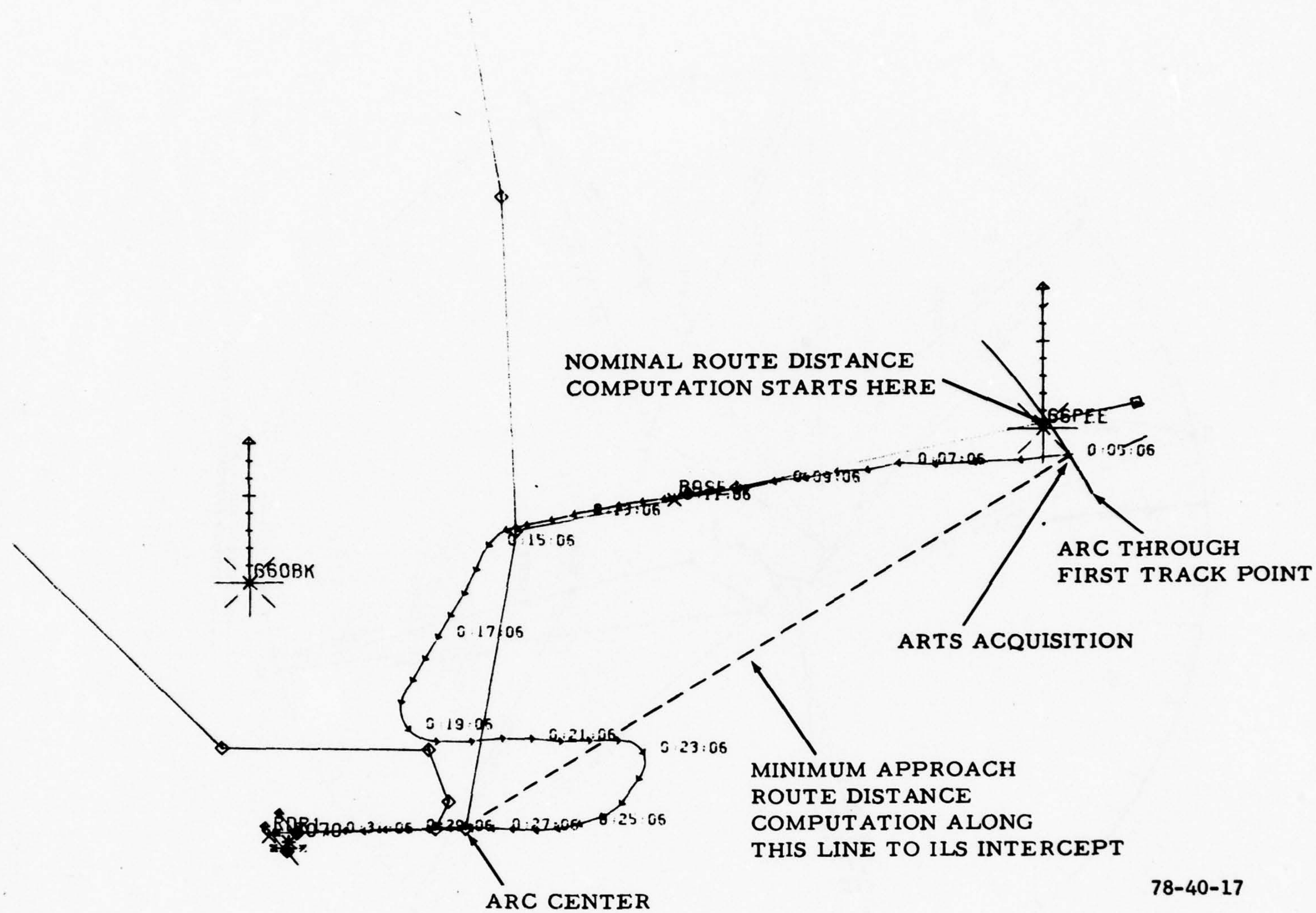


FIGURE 9. METHOD TO DERIVE COMPARABLE NOMINAL AND MINIMUM APPROACH ROUTE DISTANCES

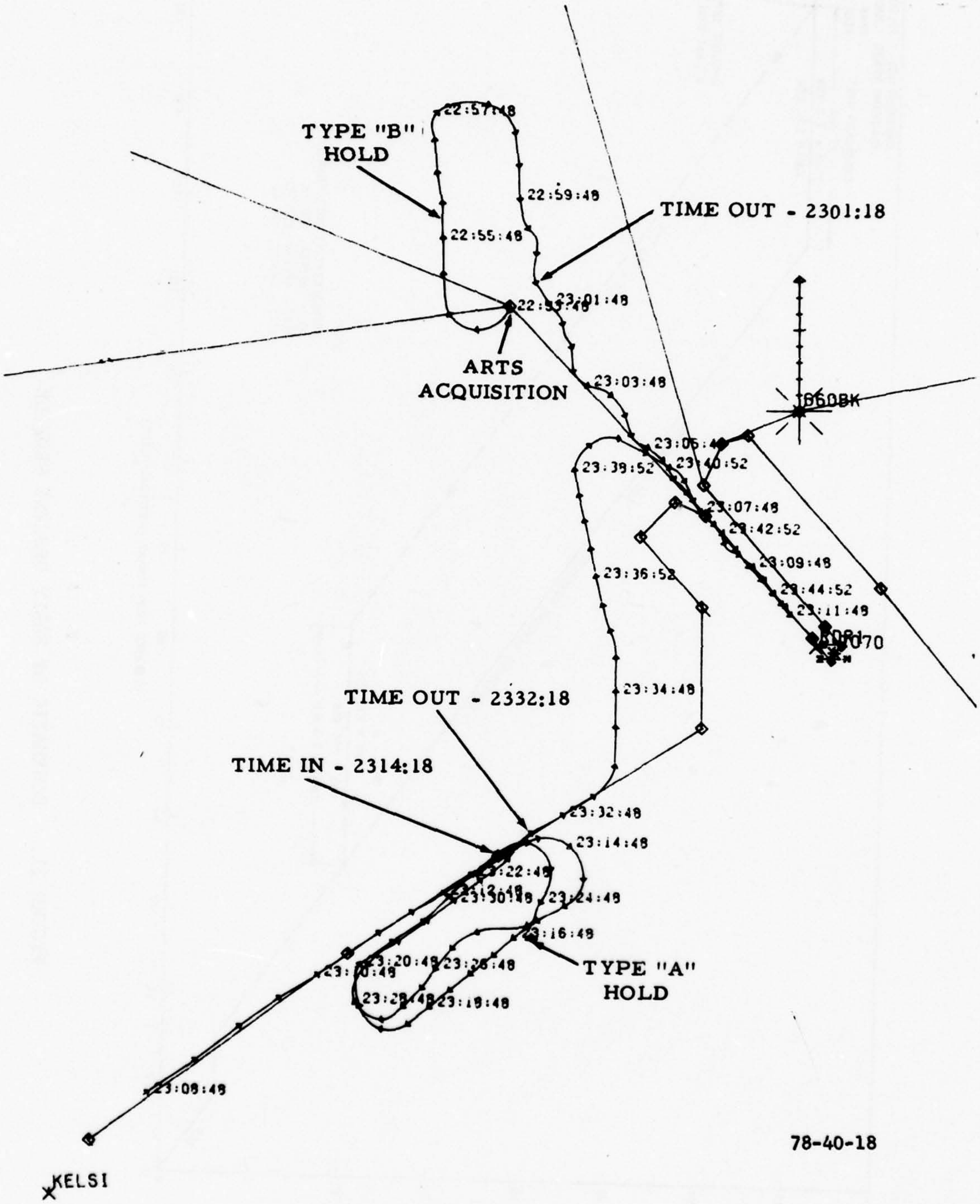


FIGURE 10. EXAMPLE OF HOLDING DATA EXTRACTION

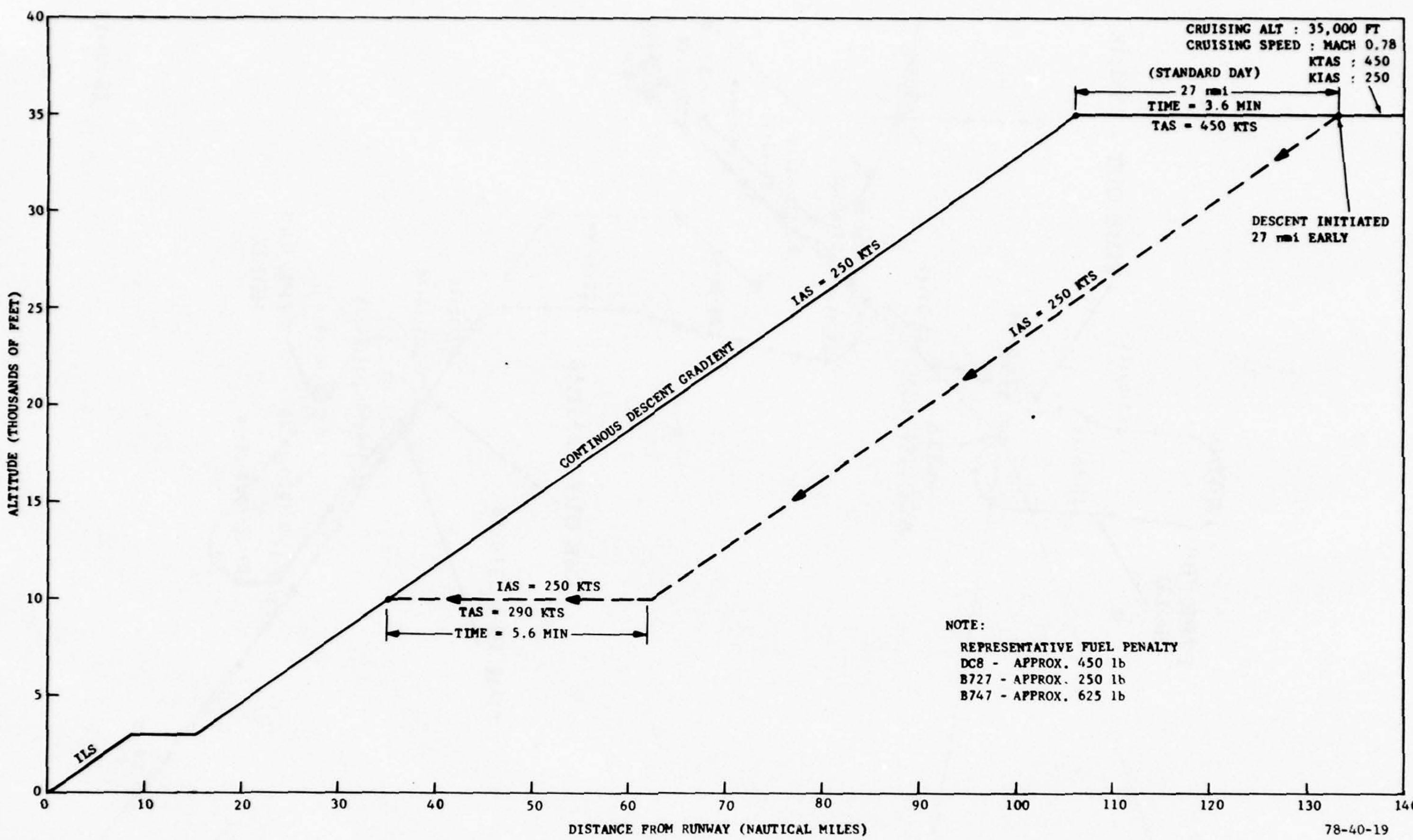
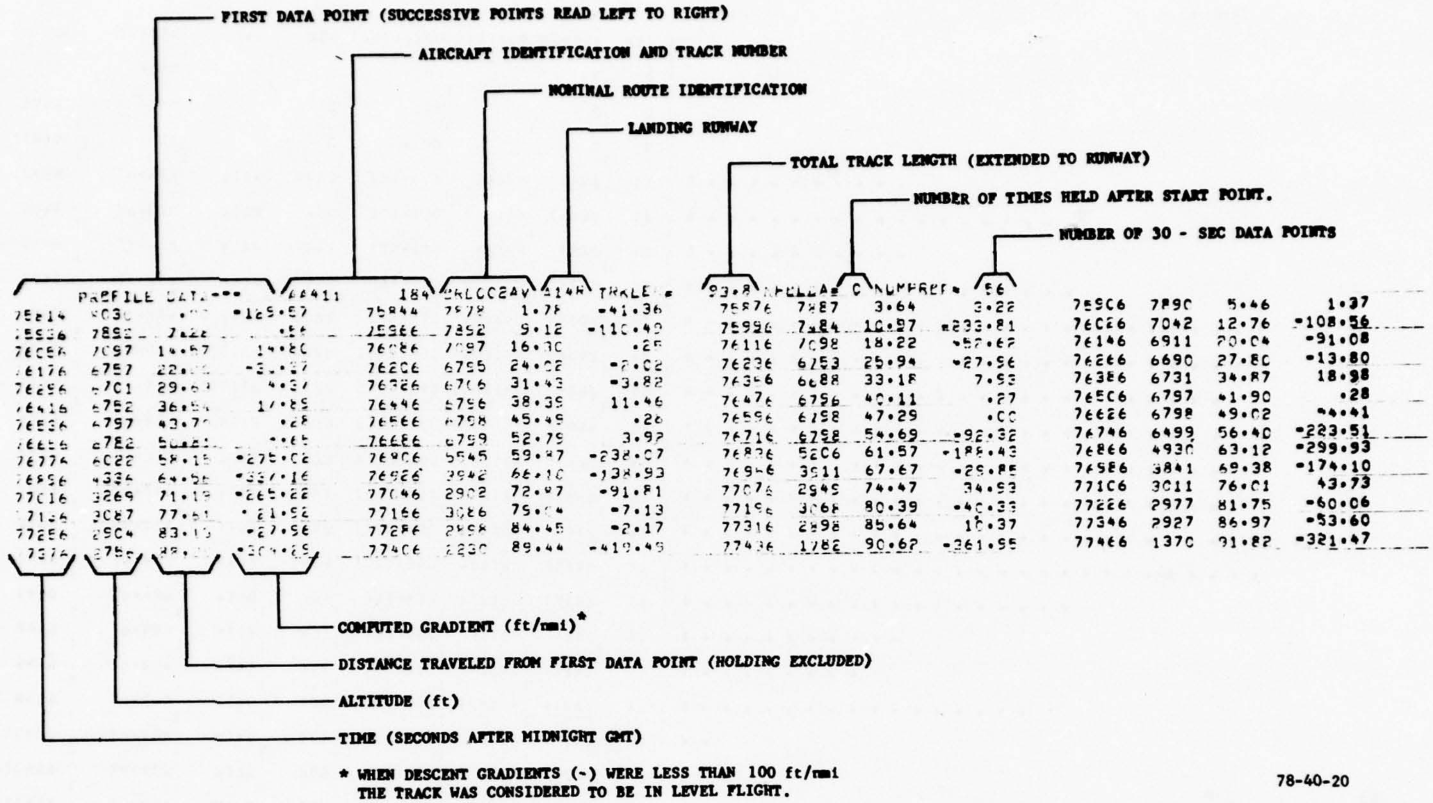


FIGURE 11. SCHEMATIC OF EARLY DESCENT PROFILE



78-40-20

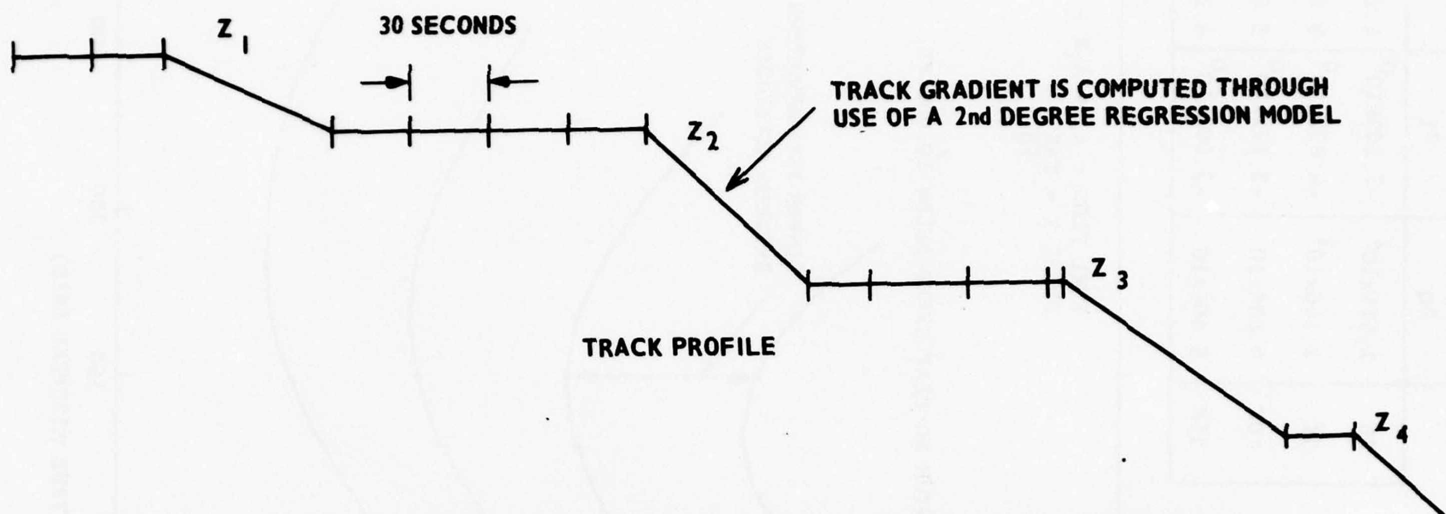
FIGURE 12. TYPICAL VERTICAL PROFILE DATA

```
***  ALTITUDE BAND SUMMARY OF LEVEL FLIGHT     ***     SAMPLE : BHC  12
     COMMENTS :  CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, C 2, C 3, N 1, N 2, N 3,
```

ALTITUDE BAND	AVERAGE NM	AVERAGE TIME	AVERAGE LBS	TOTAL NM	TOTAL TIME	TOTAL LBS	A/C COUNT	
99999 ≥ X > 11499	24.750	5:42	619	123.750	28:30	3095	5	* * * * *
11500 ≥ X > 10999	12.613	2:30	265	37.840	7:30	797	3	* * *
11000 ≥ X > 10499	20.625	4:45	501	41.250	9:30	1003	2	* *
10500 ≥ X > 9999	18.256	3:46	695	310.360	104:14	11821	17	* * * * * * * * * * * * * * * * *
10000 ≥ X > 9499	21.874	5:13	742	196.870	47:00	6681	9	* * * * * * * * *
9500 ≥ X > 8999	16.599	4:08	531	182.590	45:38	5850	11	* * * * * * * * * * *
9000 ≥ X > 8499	18.489	4:10	744	351.290	119:20	14151	19	* * * * * * * * * * * * * * * * * * *
8500 ≥ X > 7999	28.477	6:38	913	1053.660	405:50	33789	37	* *
8000 ≥ X > 7499	28.809	7:07	852	1382.830	541:56	40898	48	* *
7500 ≥ X > 6999	26.265	7:03	821	2442.630	1056:36	76390	93	* *
7000 ≥ X > 6499	26.781	7:21	973	2222.860	1010:52	80777	83	* *
6500 ≥ X > 5999	32.857	9:18	1179	2562.820	1205:34	91998	78	* *
6000 ≥ X > 5499	34.073	10:15	1195	3066.540	1523:40	107597	90	* *
5500 ≥ X > 4999	33.039	10:04	1388	1618.900	813:58	68052	49	* *
5000 ≥ X > 4499	28.384	8:51	1322	879.910	434:50	41007	31	* *
4500 ≥ X > 3999	20.764	6:37	558	394.510	205:58	18208	19	* * * * * * * * * * * * * * * * * * *
4000 ≥ X > 3499	11.438	4:02	511	125.820	44:26	5627	11	* * * * * * * * * * *
3500 ≥ X > 2999	16.270	5:38	825	309.130	147:16	15682	19	* * * * * * * * * * * * * * * * * * *
3000 ≥ X > 2499	15.927	5:24	1050	175.200	59:28	11557	11	* * * * * * * * * * *
2500 ≥ X > 1999	.000		0	.000		0	0	
2000 ≥ X > 1499	.000		0	.000		0	0	
1500 ≥ X > 0	.000		0	.000		0	0	
99999 ≥ X > 0	27.526	7:42	999	17478.762	8132:06	634988	635	

78-40-21

FIGURE 13. LEVEL-FLIGHT DATA SUMMARY



1. FUEL BURN IS COMPUTED AT 30-SECOND INTERVALS ON LEVEL SEGMENTS OF THE TRACK PROFILE AS A FUNCTION OF (a) AIRCRAFT TYPE, (b) ALTITUDE, (c) SPEED. GRADIENTS OF LESS THAN 100 FT. PER NAUTICAL MILE ARE CONSIDERED LEVEL.
2. FUEL BURN AND LEVEL DISTANCE ARE SUMMED FOR ALL LEVEL SEGMENTS.
3. A WEIGHTED FUEL FLOW RATE IS DERIVED BY DIVIDING TOTAL FUEL BURN BY TOTAL LEVEL DISTANCES.
4. THE WEIGHTED FUEL FLOW RATE (lb/nmi) IS APPLIED TO EXCESS MILEAGE TO DERIVE EXCESS FUEL CONSUMPTION.

78-40-23

FIGURE 14. METHOD FOR DERIVING A WEIGHTED FUEL FLOW RATE

	A_0	A_1	A_2
SL	1.511×10^2	-7.209×10^0	1.270×10^{-1}
5K	1.160×10^2	-4.822×10^0	8.002×10^{-2}
10K	9.836×10	-3.722×10^0	5.813×10^{-2}
15K	8.604×10	-3.002×10^0	4.368×10^{-2}

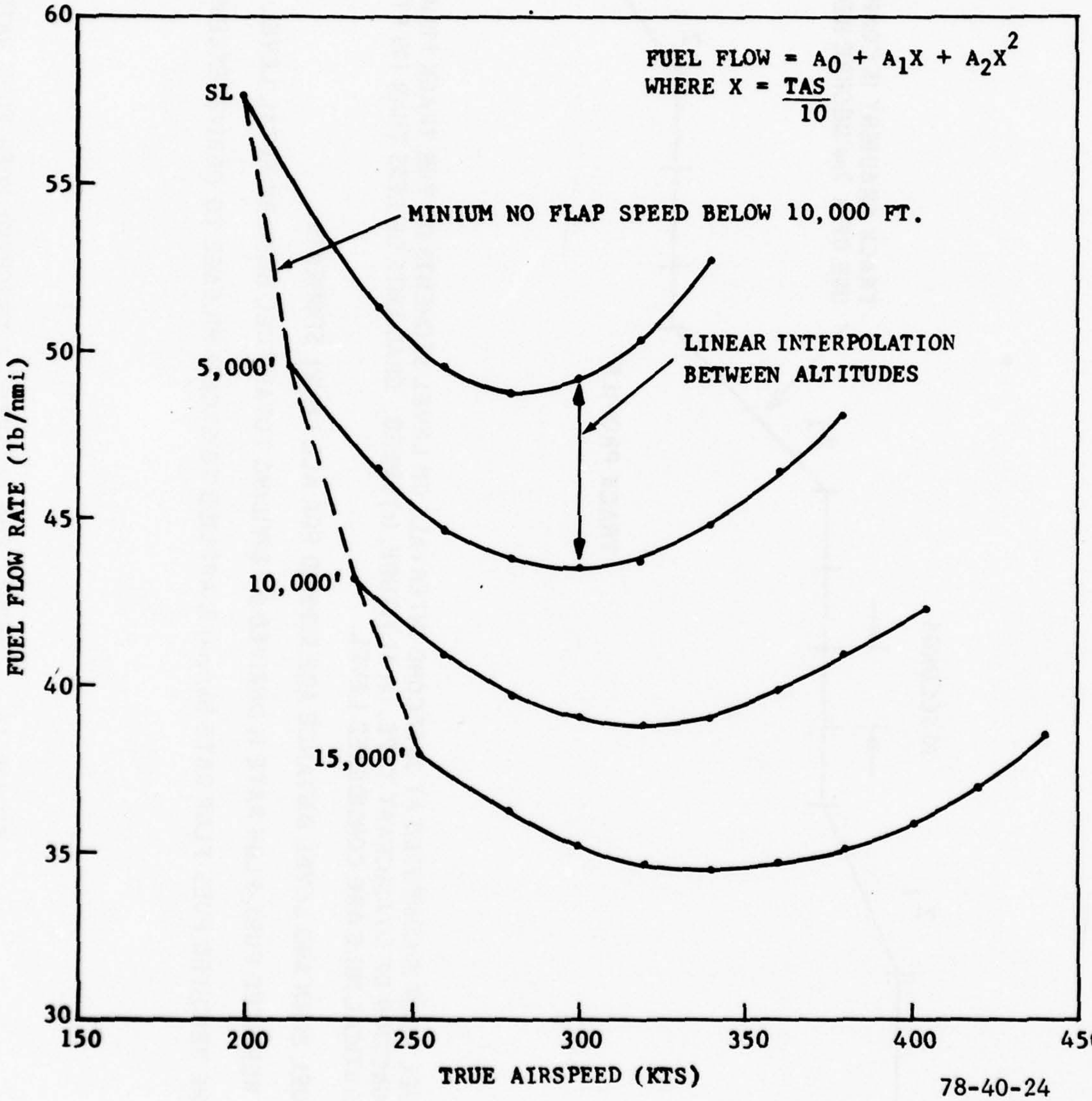


FIGURE 15. EXAMPLE OF FUEL FLOW RATE COMPUTATION (DC8--220,000 lb--NO FLAPS)

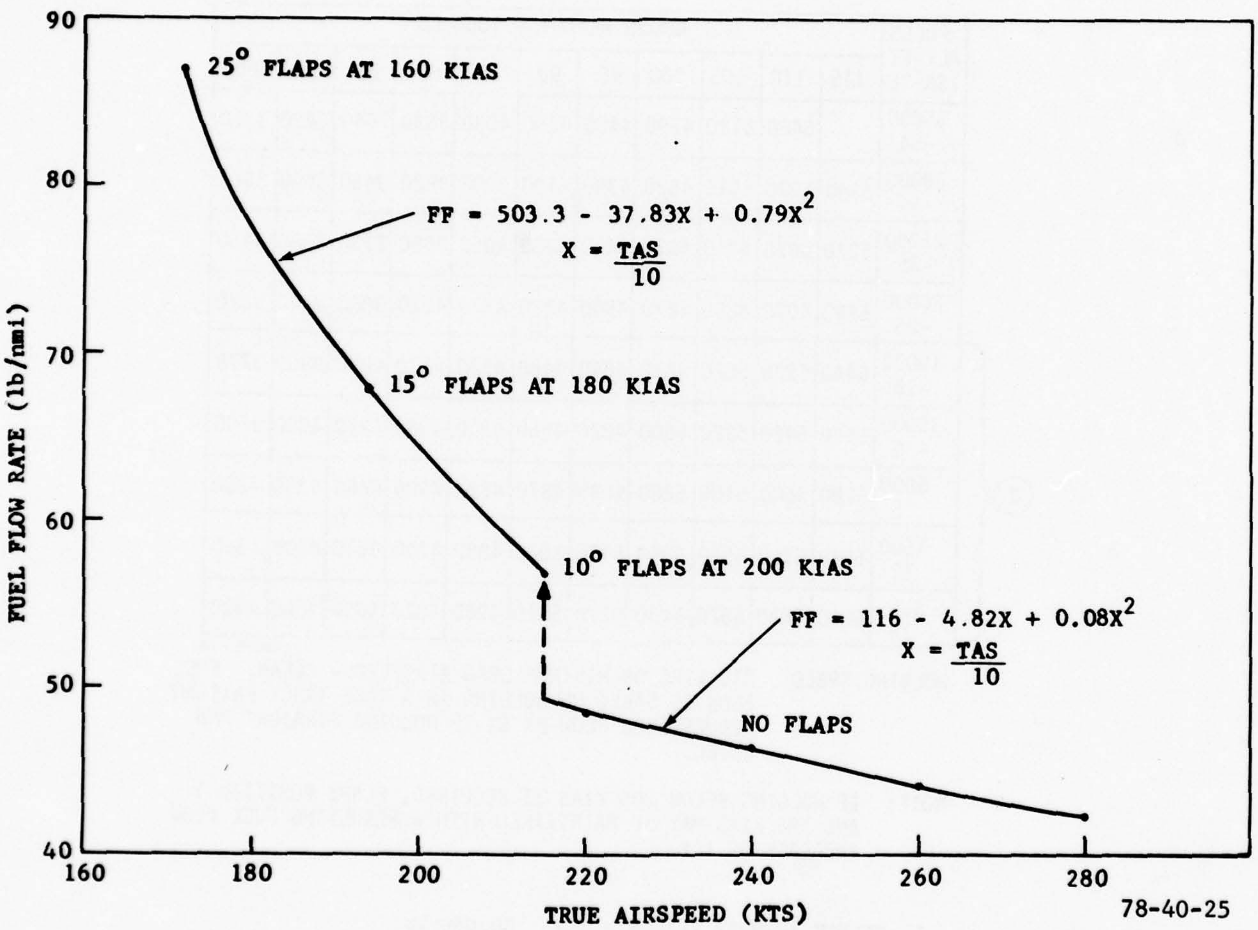


FIGURE 16. EFFECT OF FLAPS ON FUEL FLOW RATE
(DC8--220,000 lb--5,000 ft)

FUEL FLOW BASED ON ISA
ADJUST FUEL FLOW ± 1%
PER ± 5°C ISA DEVIATION

TOTAL FUEL FLOW - LB/HR

1

PRESS ALT-FT ISA-°C	GROSS WEIGHT - 1000 LB										
	115	110	105	100	95	90	85	80	75	70	65
35000 -54		5480	5120	4790	4480	4250	4030	3830	3640	3470	3310
30000 -44	5340	5070	4810	4620	4390	4190	3990	3820	3660	3500	3360
25000 -35	5270	5070	4850	4620	4410	4230	4050	3890	3730	3580	3450
20000 -25	5290	5070	4850	4670	4500	4330	4170	4020	3880	3740	3620
15000 -15	5440	5230	5020	4810	4640	4480	4320	4170	4030	3900	3770
10000 - 5	5590	5420	5220	5000	4820	4660	4510	4360	4220	4090	3990
5000 5	5780	5600	5400	5200	5030	4870	4720	4590	4460	4330	4200
1500 12	5940	5760	5550	5340	5170	5040	4890	4740	4610	4490	4360
S.L. 15	6030	5830	5620	5430	5270	5110	4960	4820	4690	4560	4420

2

327-3.1-13

HOLDING SPEED: 210 KIAS OR MINIMUM DRAG AIRSPEED - CLEAN. FUEL FLOW IS BASED ON HOLDING IN A RACE TRACK PATTERN. REDUCE FUEL FLOW BY 5% IF HOLDING STRAIGHT AND LEVEL.

NOTE: IF HOLDING BELOW 200 KIAS IS REQUIRED, FLAPS POSITION 1 AND 190 KIAS MAY BE MAINTAINED WITH A RESULTING FUEL FLOW INCREASE OF 10%.

1. **SELECT ASSUMED WEIGHT - i.e., 90,000 lb.**
2. **SELECT ALTITUDE BAND - i.e., 0 - 15,000 ft.**
3. **USE REGRESSION ANALYSIS TO FIND FUEL FLOW (FF) EQUATION- i.e., FF (lb/hr) = $5112 - 5.125\,Z + .006\,Z^2$ WHERE $Z = \frac{ALT}{100}$**

78-40-26

FIGURE 17. METHOD FOR DERIVING HOLDING FUEL FLOW RATE

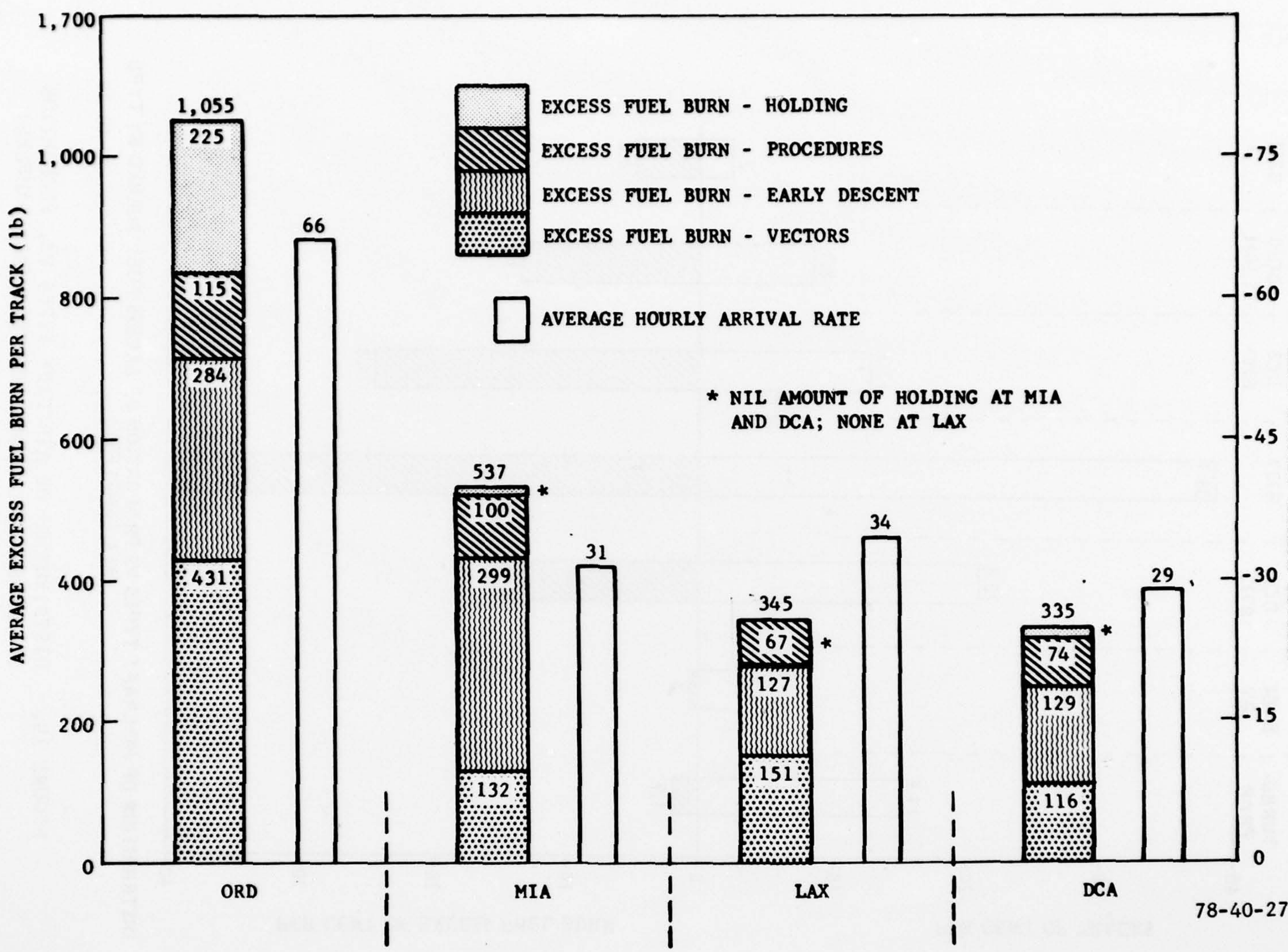


FIGURE 18. EXCESS FUEL CONSUMPTION AND ARRIVAL RATES FOR MAJOR AIRPORTS IN THE SAMPLE DATA

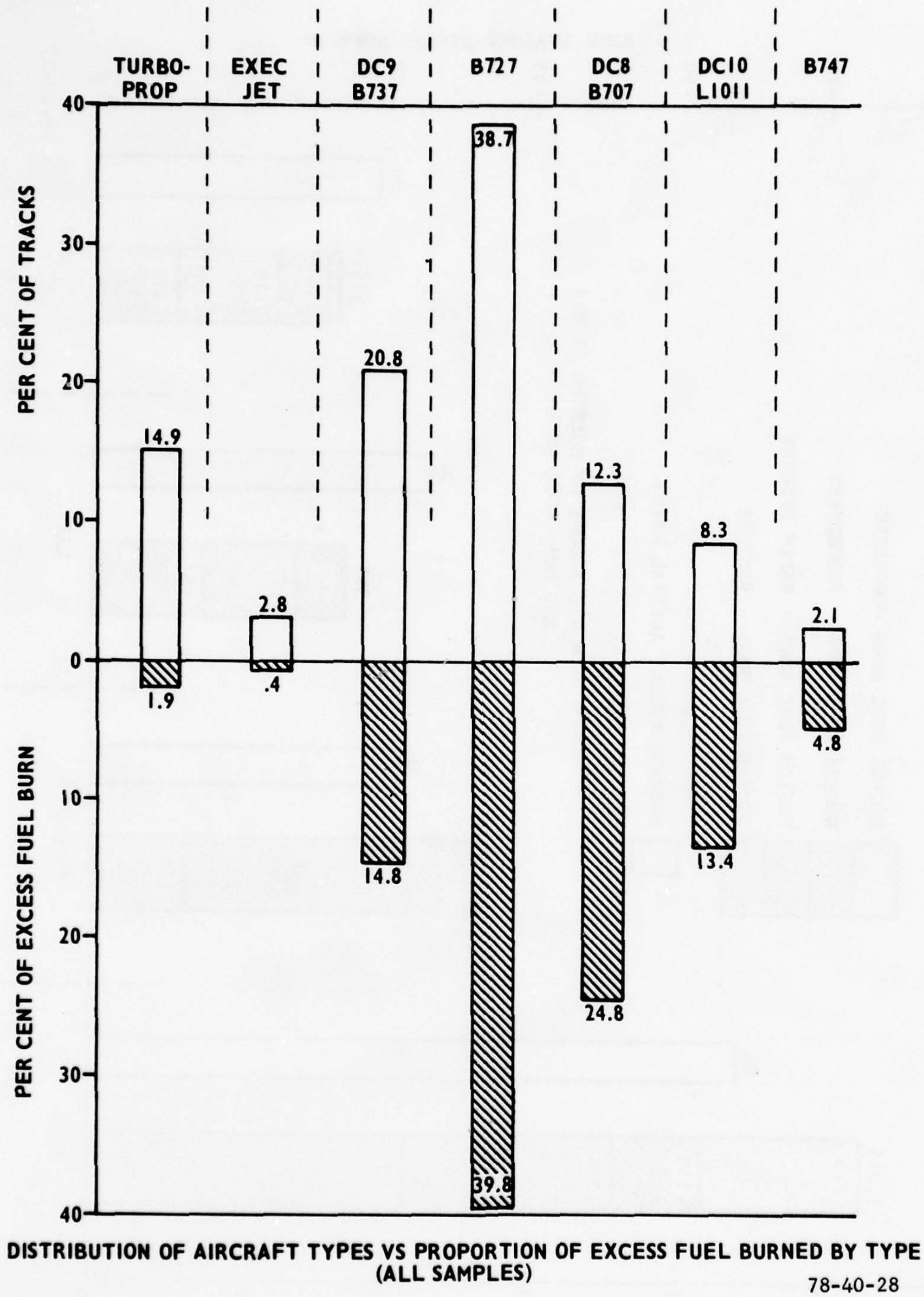


FIGURE 19. DISTRIBUTION OF AIRCRAFT TYPES VS. PROPORTION OF EXCESS FUEL BURNED BY TYPE (ALL SAMPLES)

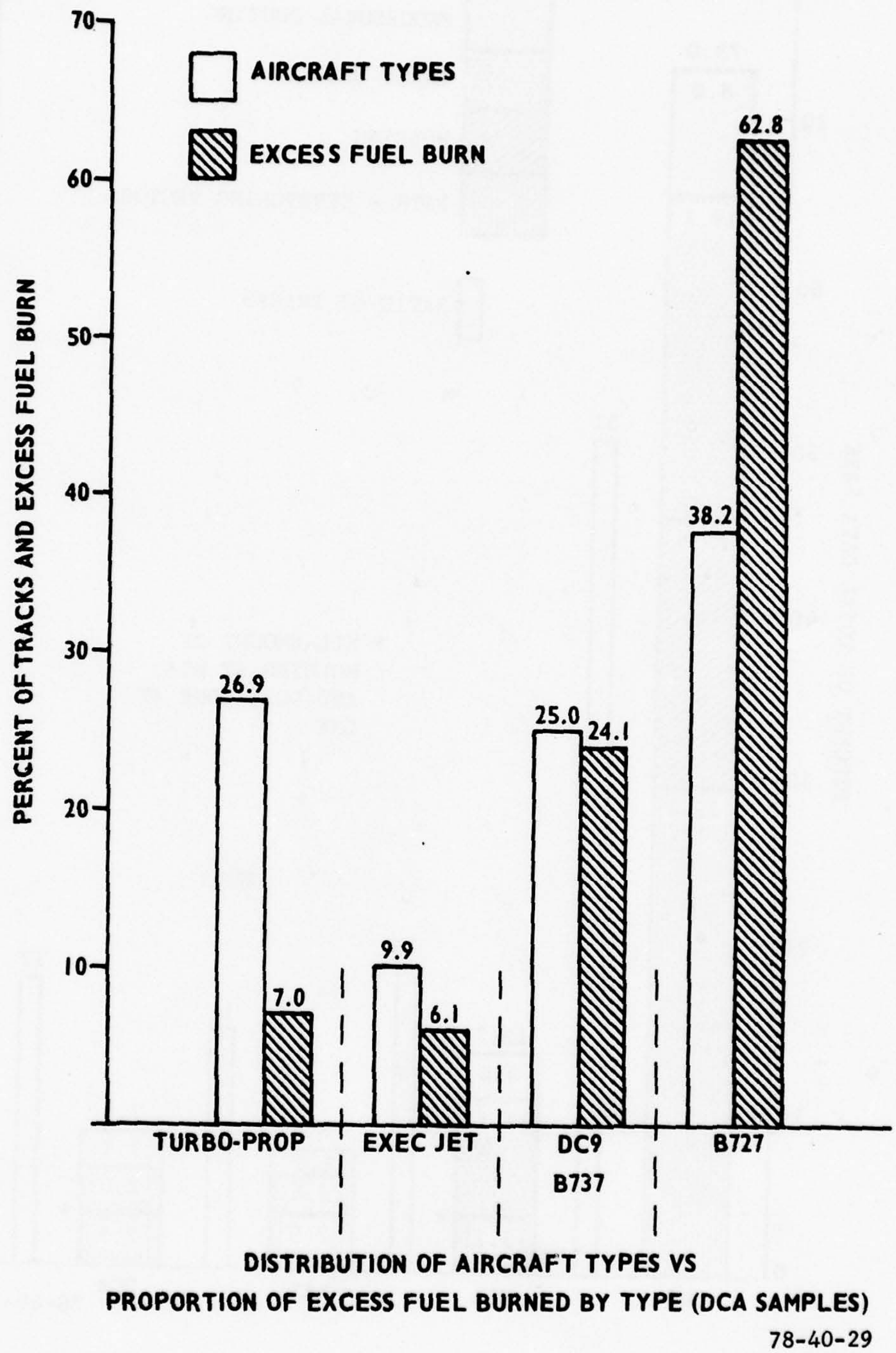


FIGURE 20. DISTRIBUTION OF AIRCRAFT TYPES VS. PROPORTION OF EXCESS FUEL BURNED BY TYPE (DCA SAMPLES)

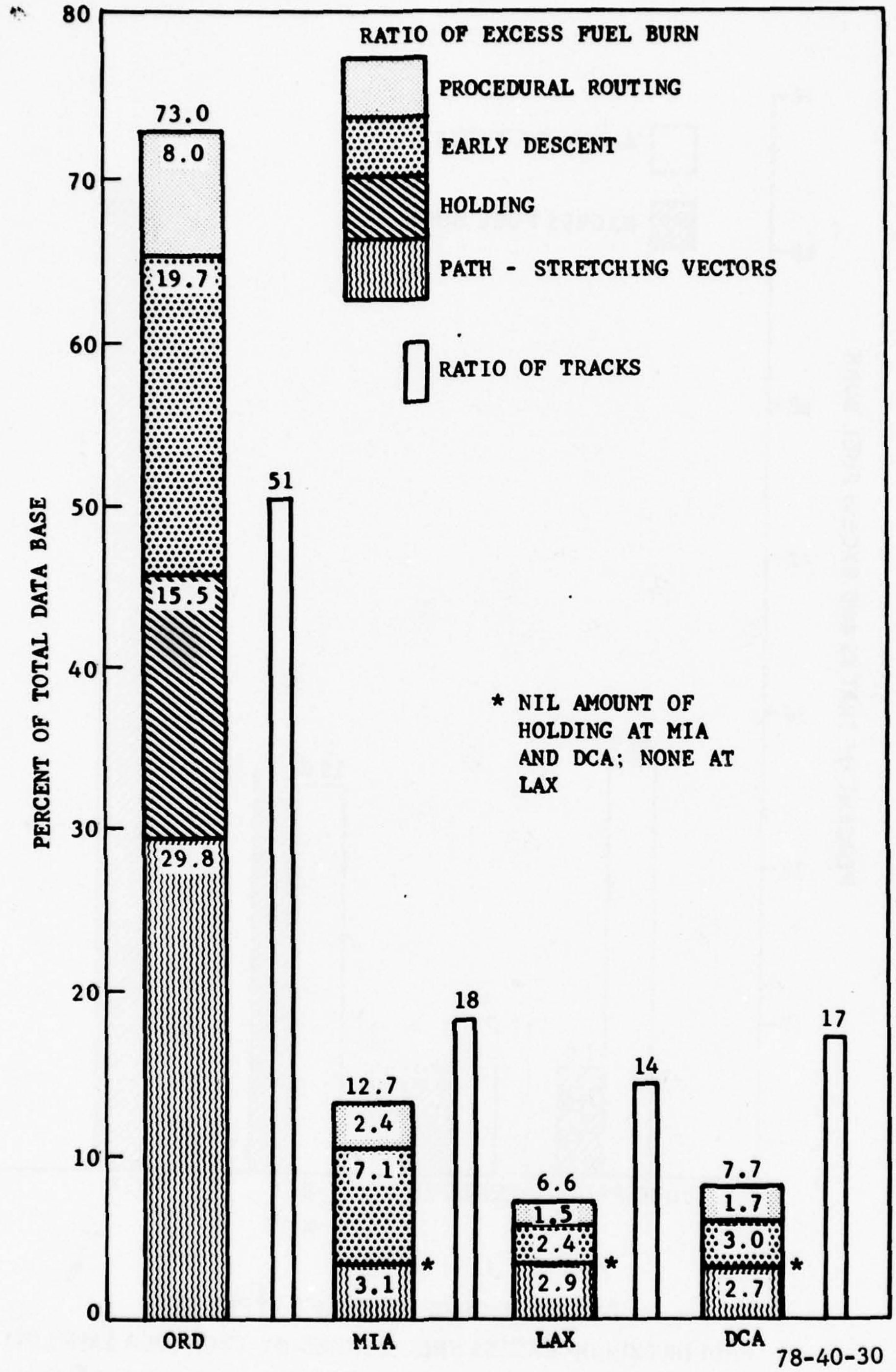


FIGURE 21. RATIO OF EXCESS FUEL CONSUMPTION AND NUMBER OF TRACKS FOR EACH AIRPORT WITH RESPECT TO THE TOTAL DATA BASE

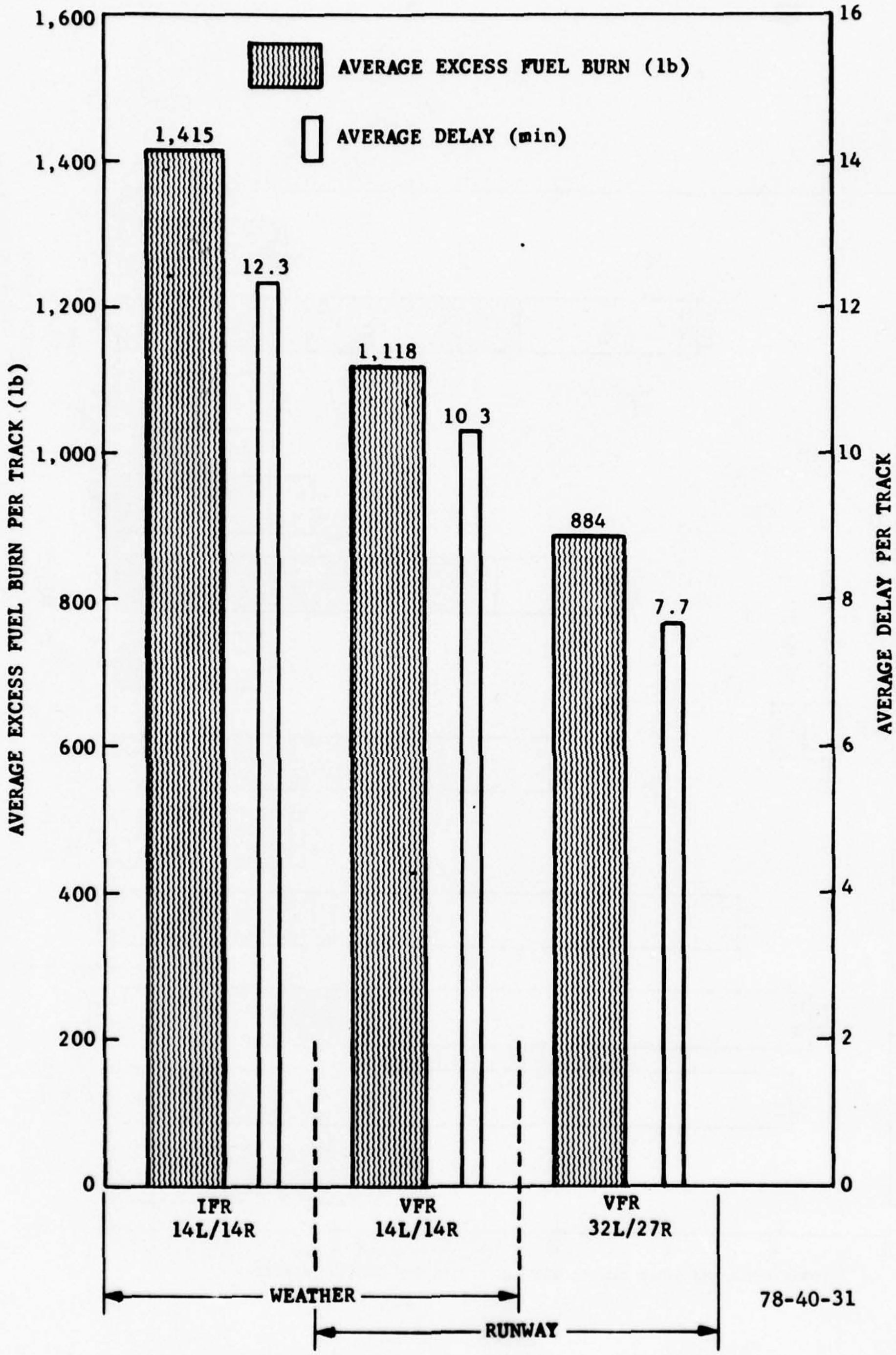


FIGURE 22. EFFECT OF WEATHER AND RUNWAY CONFIGURATION ON DELAY AND EXCESS FUEL CONSUMPTION (ORD)

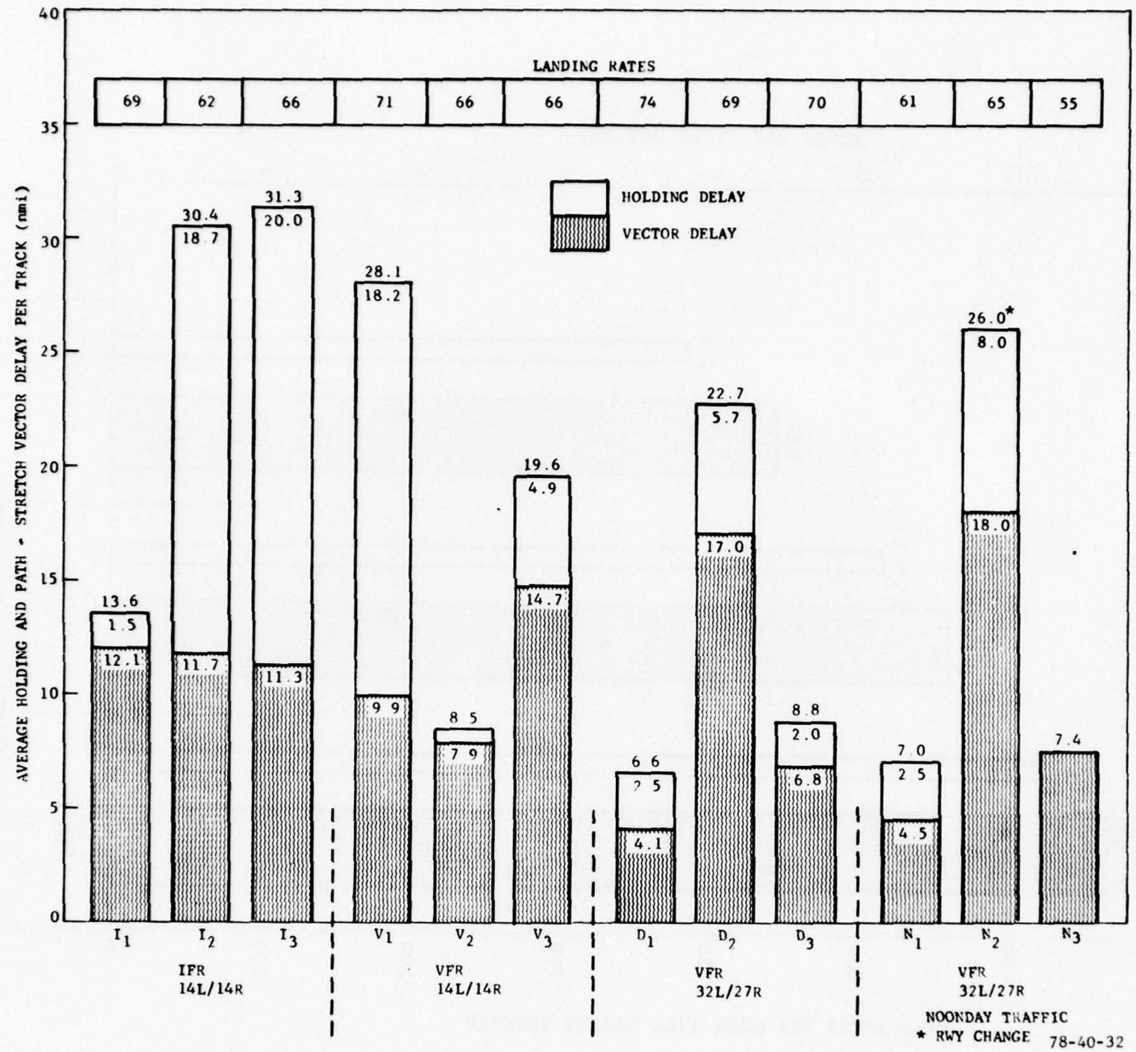


FIGURE 23. SAMPLE-TO-SAMPLE VARIATION IN HOLDING AND PATH-STRETCHING VECTOR DELAY (ORD)

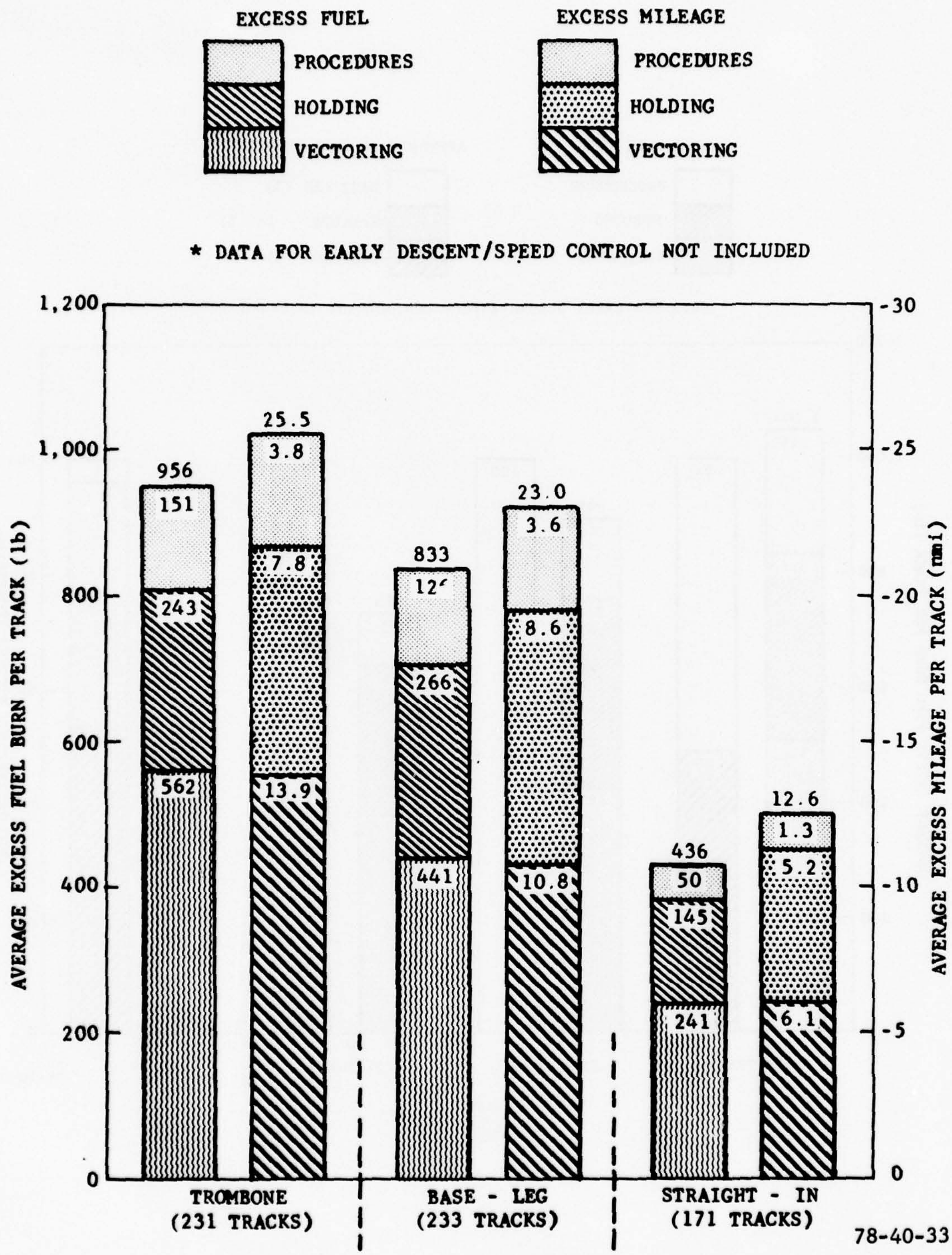


FIGURE 24. EFFECT OF APPROACH PATTERN GEOMETRY ON EXCESS MILEAGE AND EXCESS FUEL CONSUMPTION (ORD)

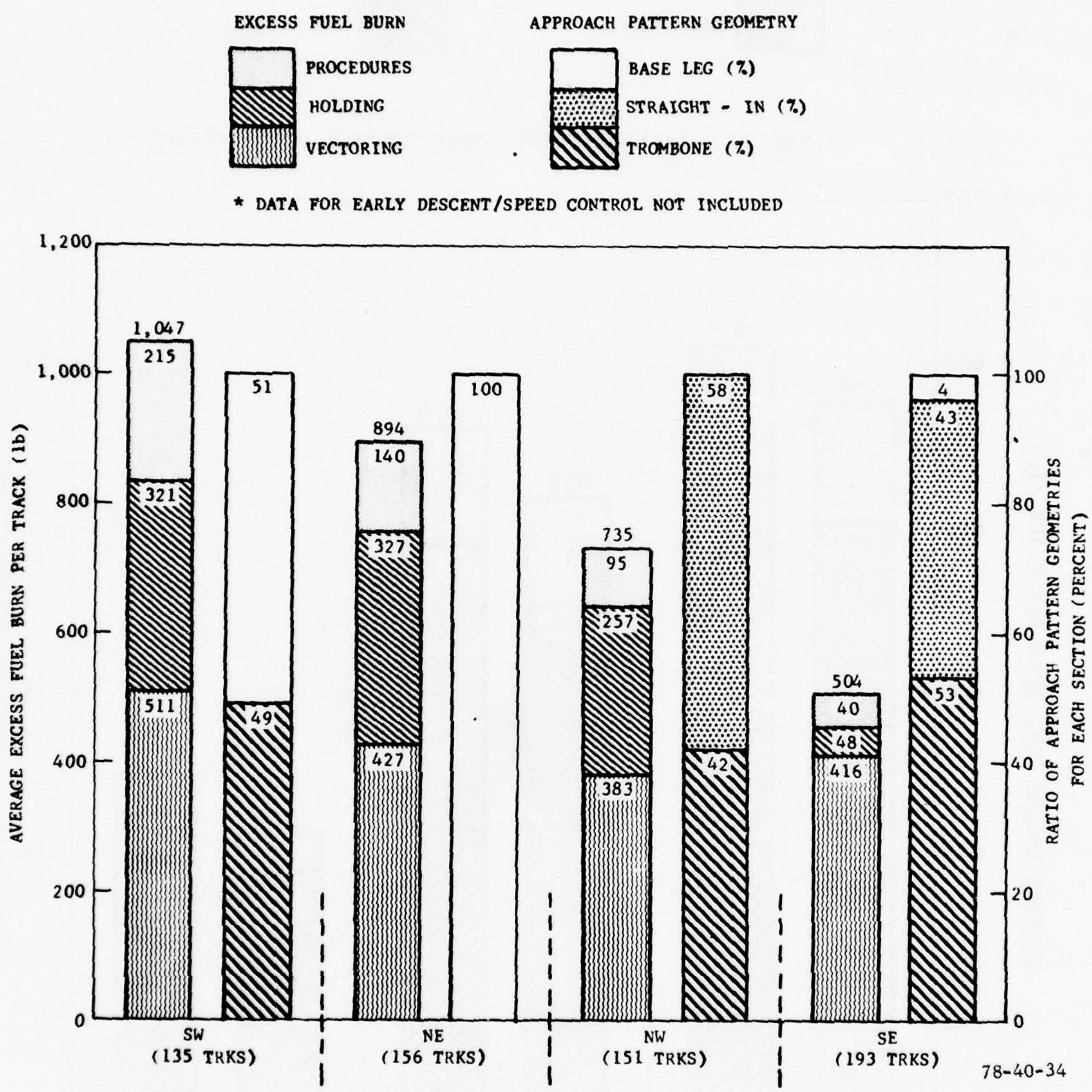


FIGURE 25. EFFECT OF ENTRY SECTOR ON EXCESS FUEL CONSUMPTION (ORD)

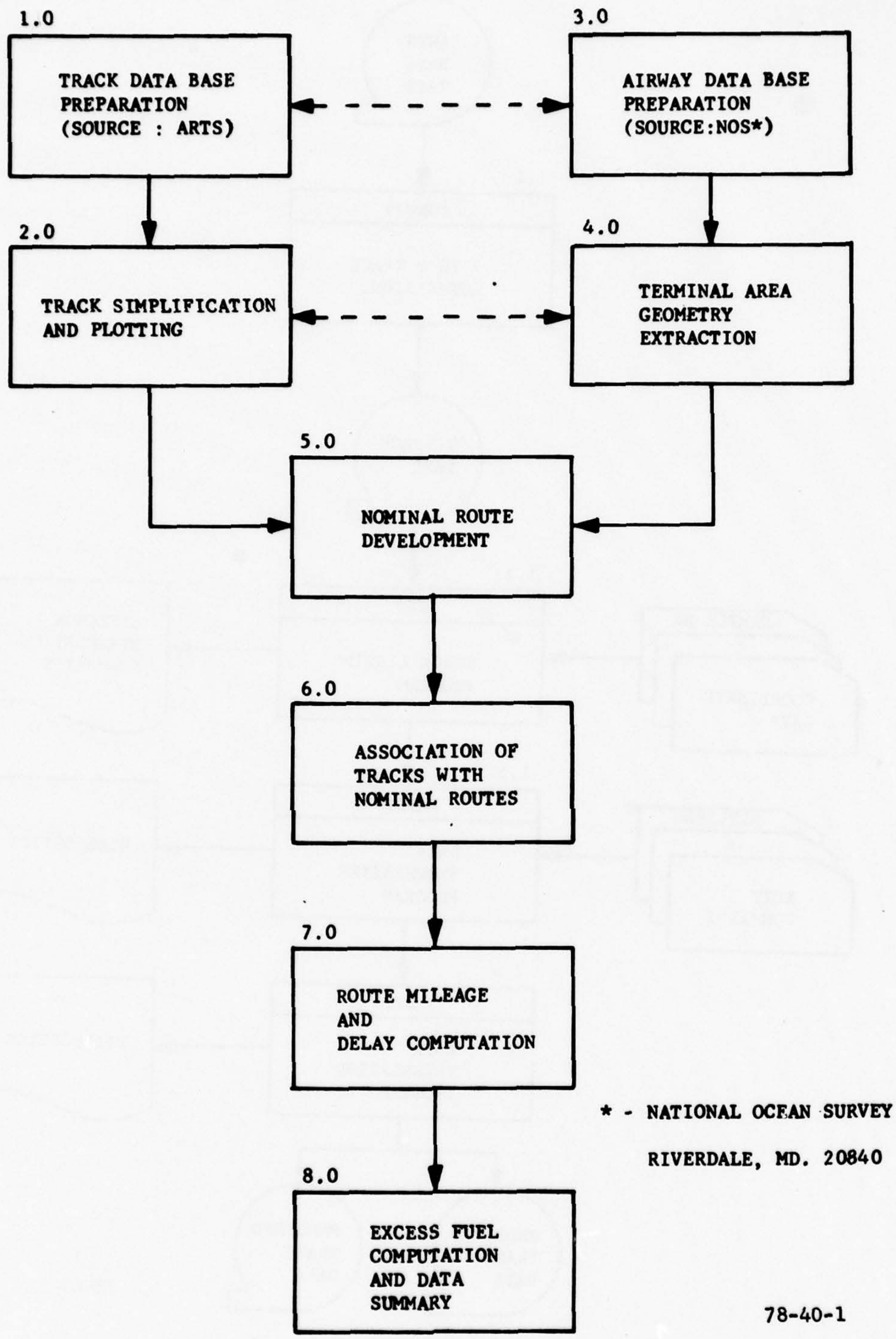


FIGURE 26. METHODOLOGY TO COMPUTE DELAY AND EXCESS FUEL CONSUMPTION IN THE TERMINAL AREA

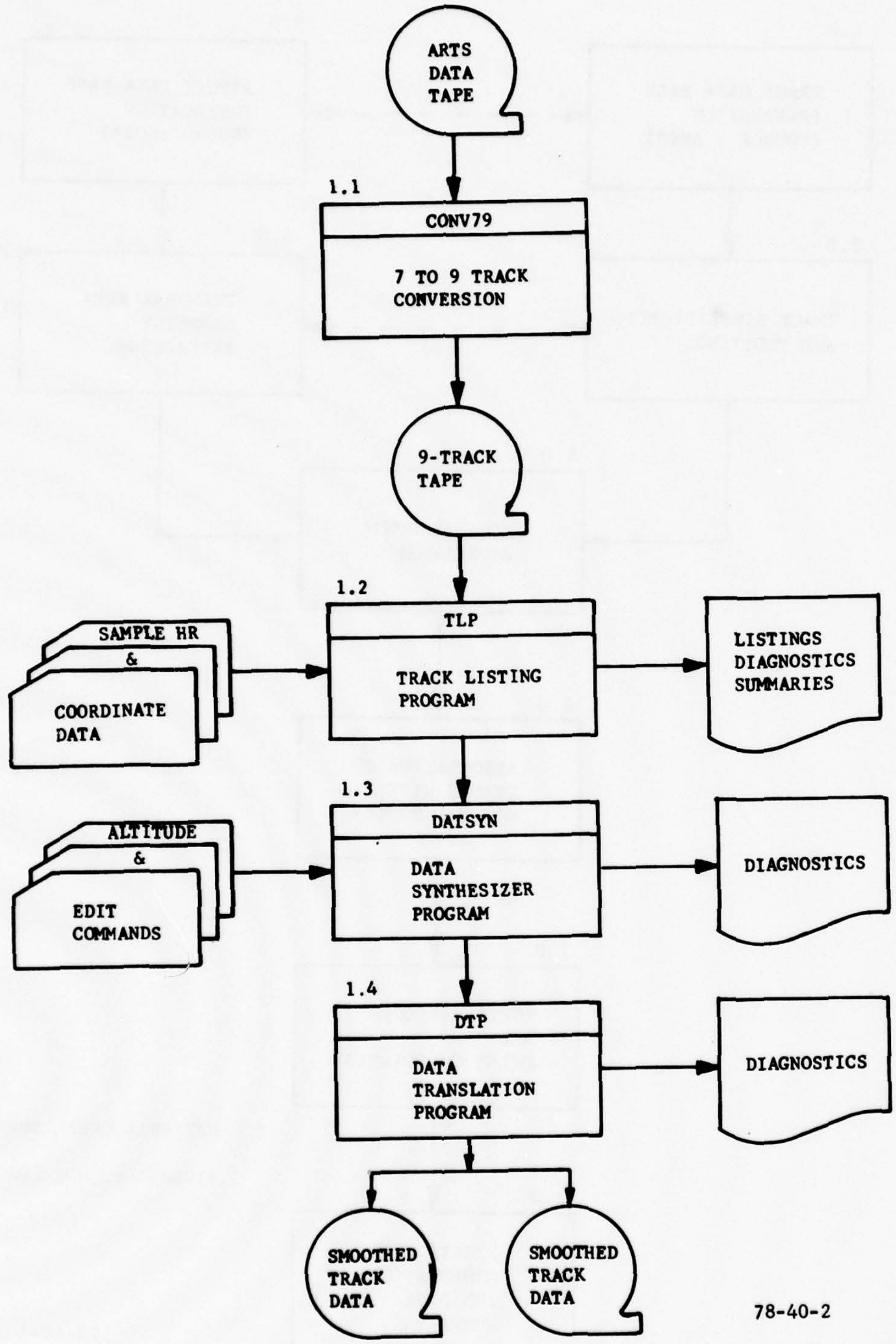


FIGURE 27. TRACK DATA BASE PREPARATION

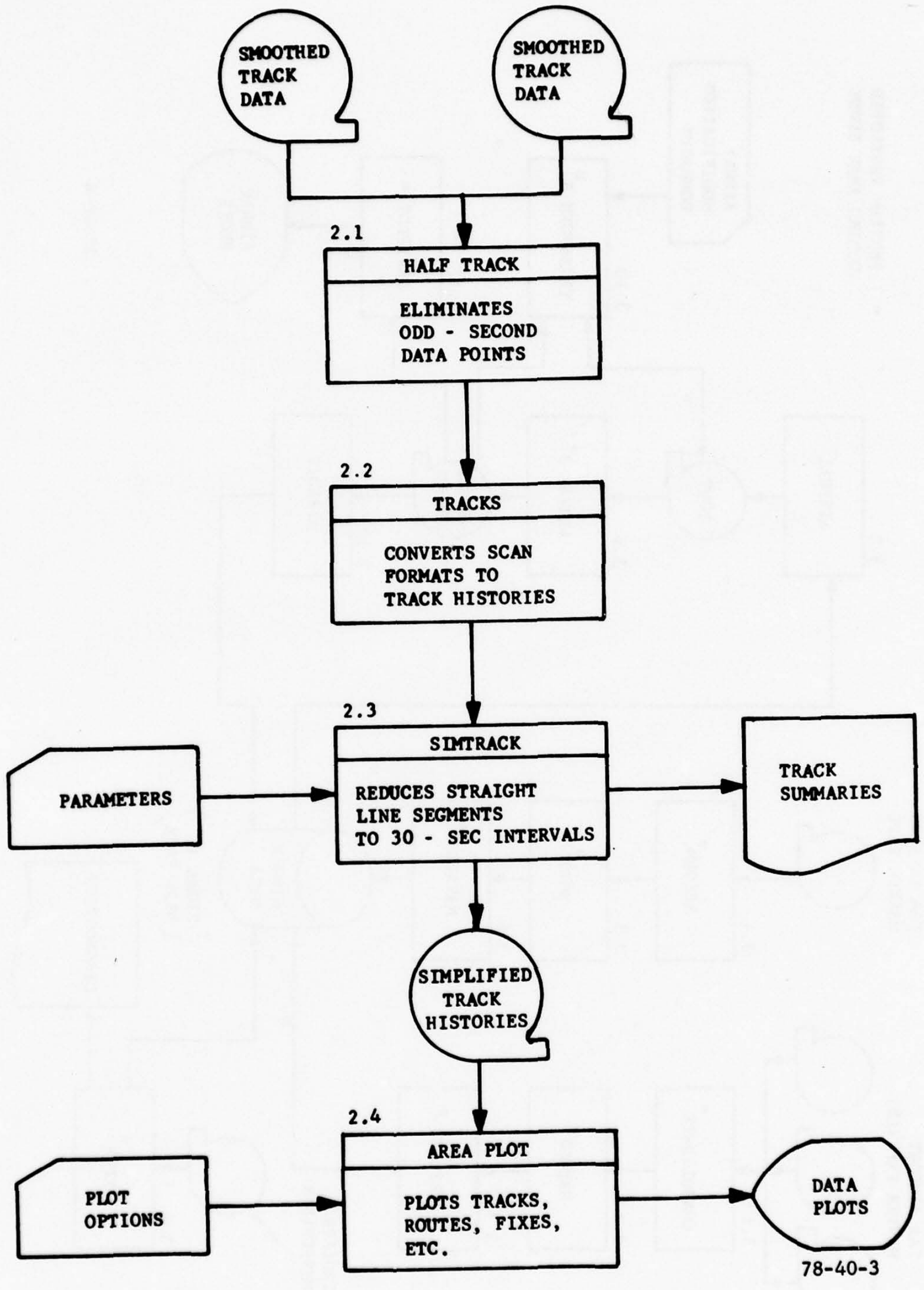


FIGURE 28. TRACK SIMPLIFICATION AND PLOTTING

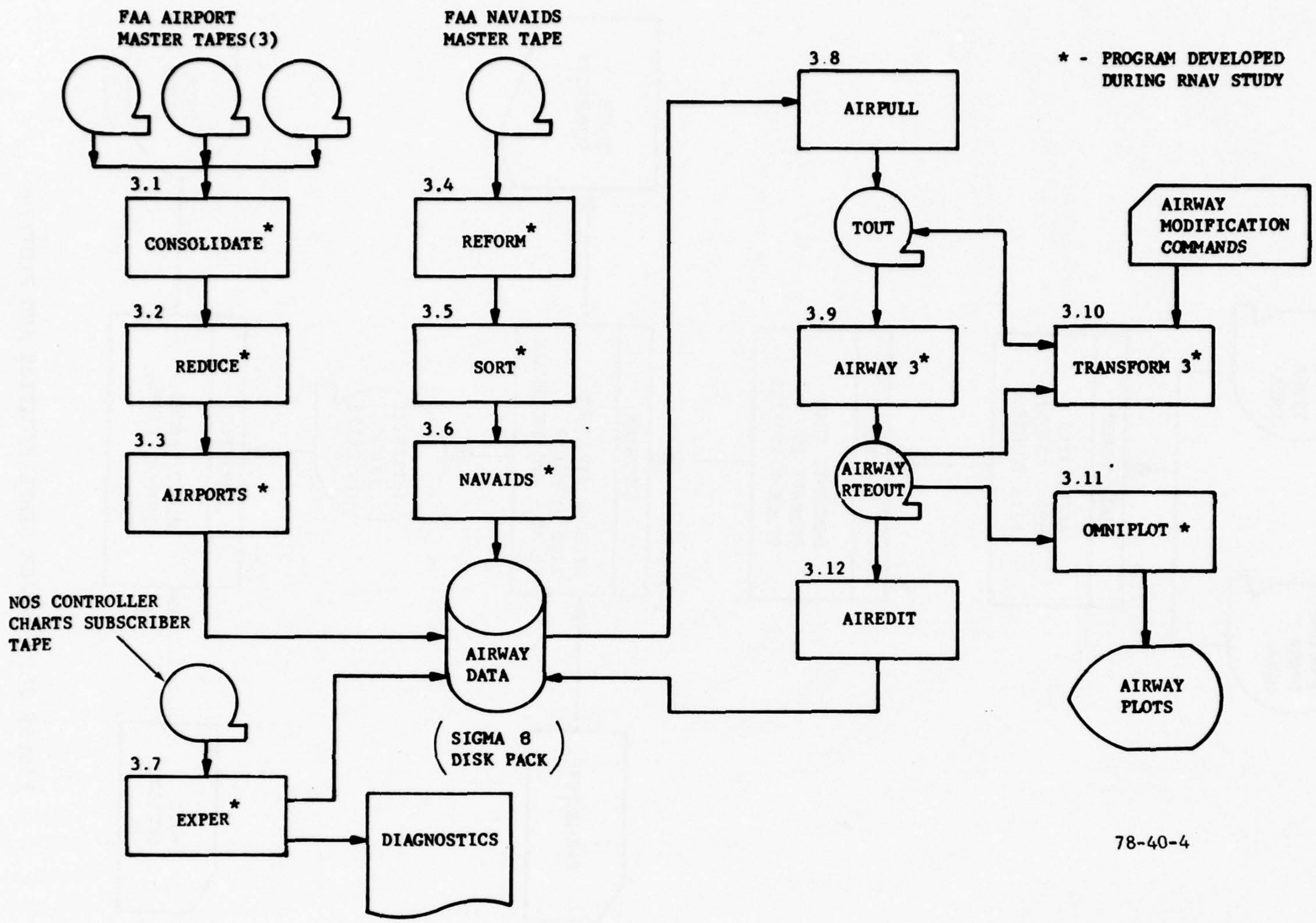


FIGURE 29. AIRWAY DATA BASE PREPARATION

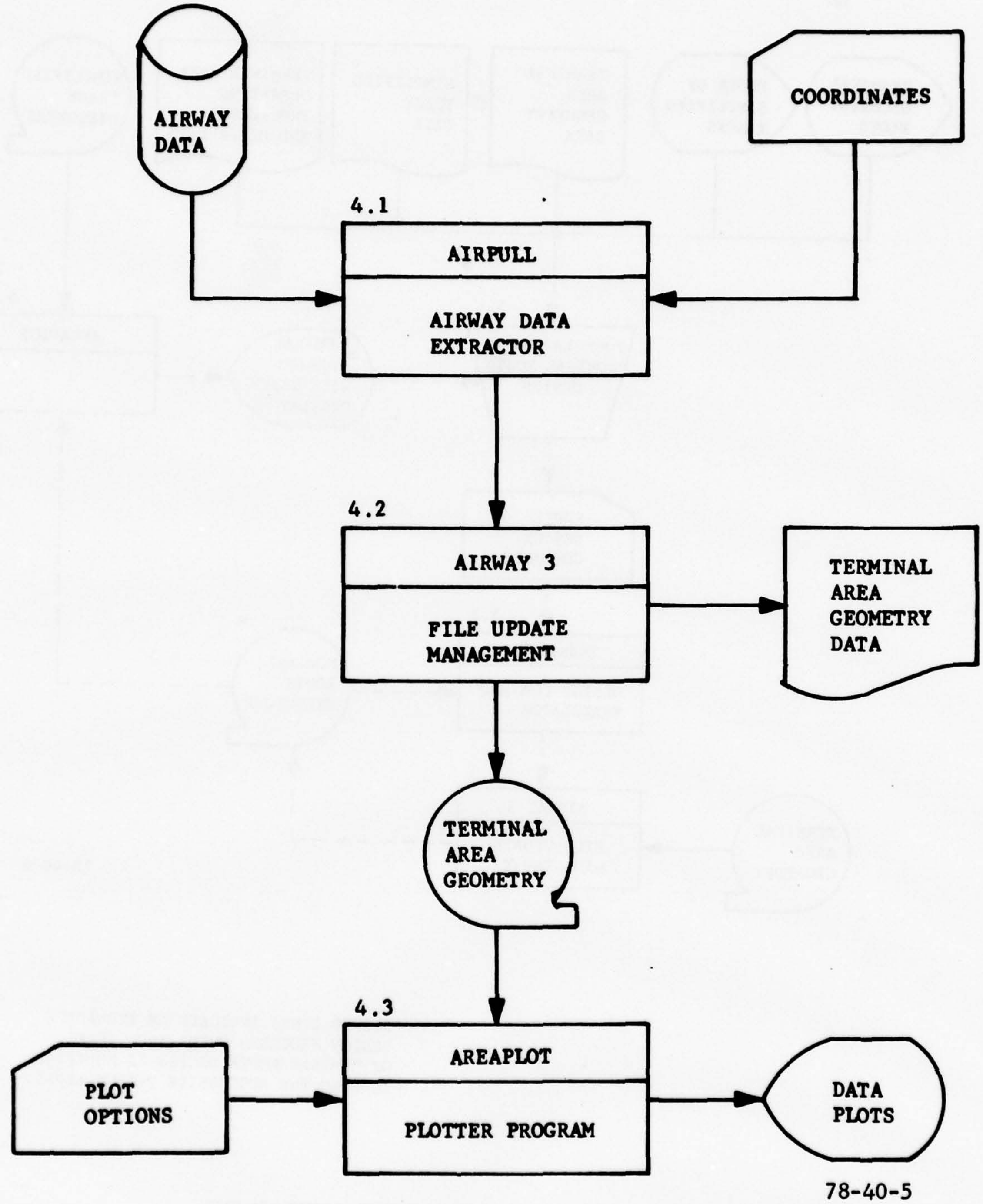
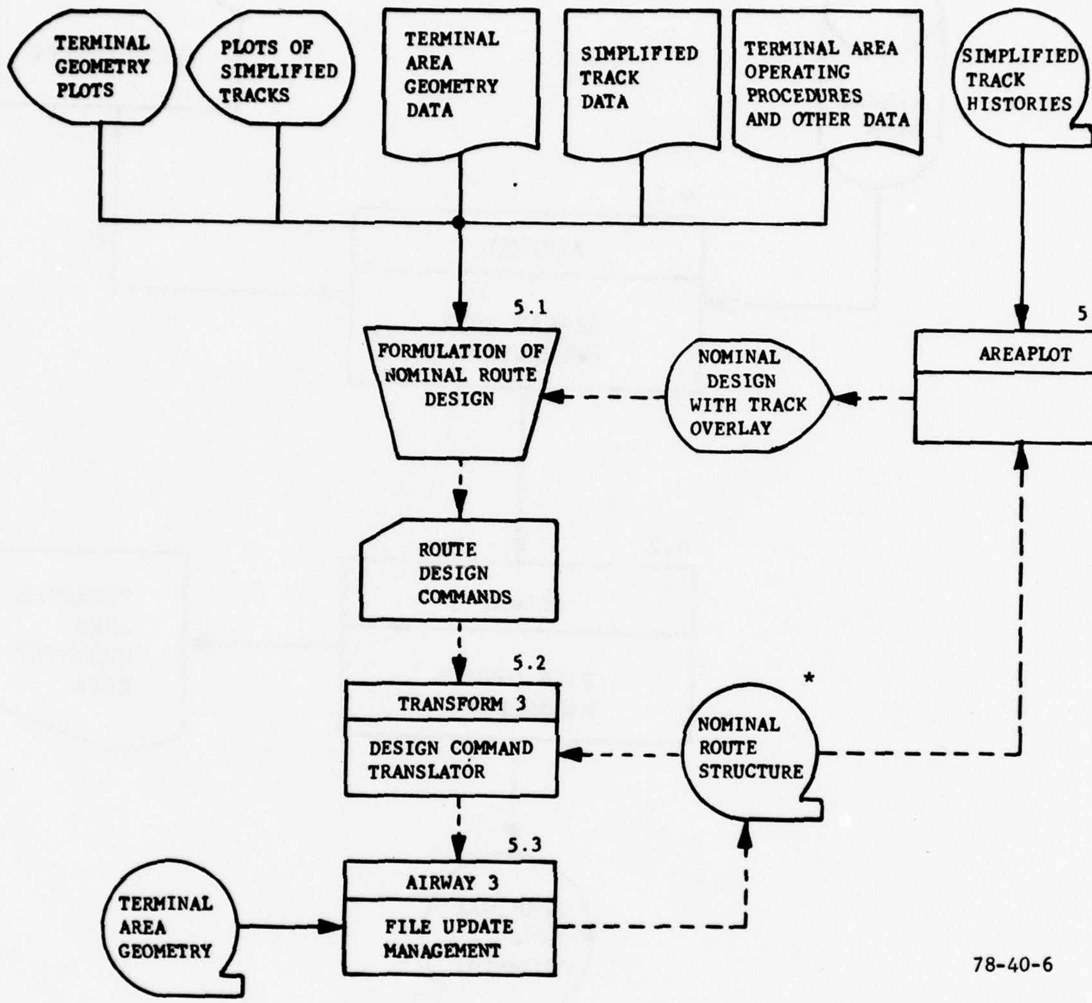


FIGURE 30. TERMINAL AREA GEOMETRY EXTRACTION



*DASHED LINES INDICATE AN ITERATIVE DESIGN PROCESS, WHERE EACH LEVEL OF NOMINAL ROUTE DESIGN IS MODIFIED TO FORM THE SUCCESSIVE DESIGN LEVEL.

FIGURE 31. NOMINAL ROUTE DEVELOPMENT

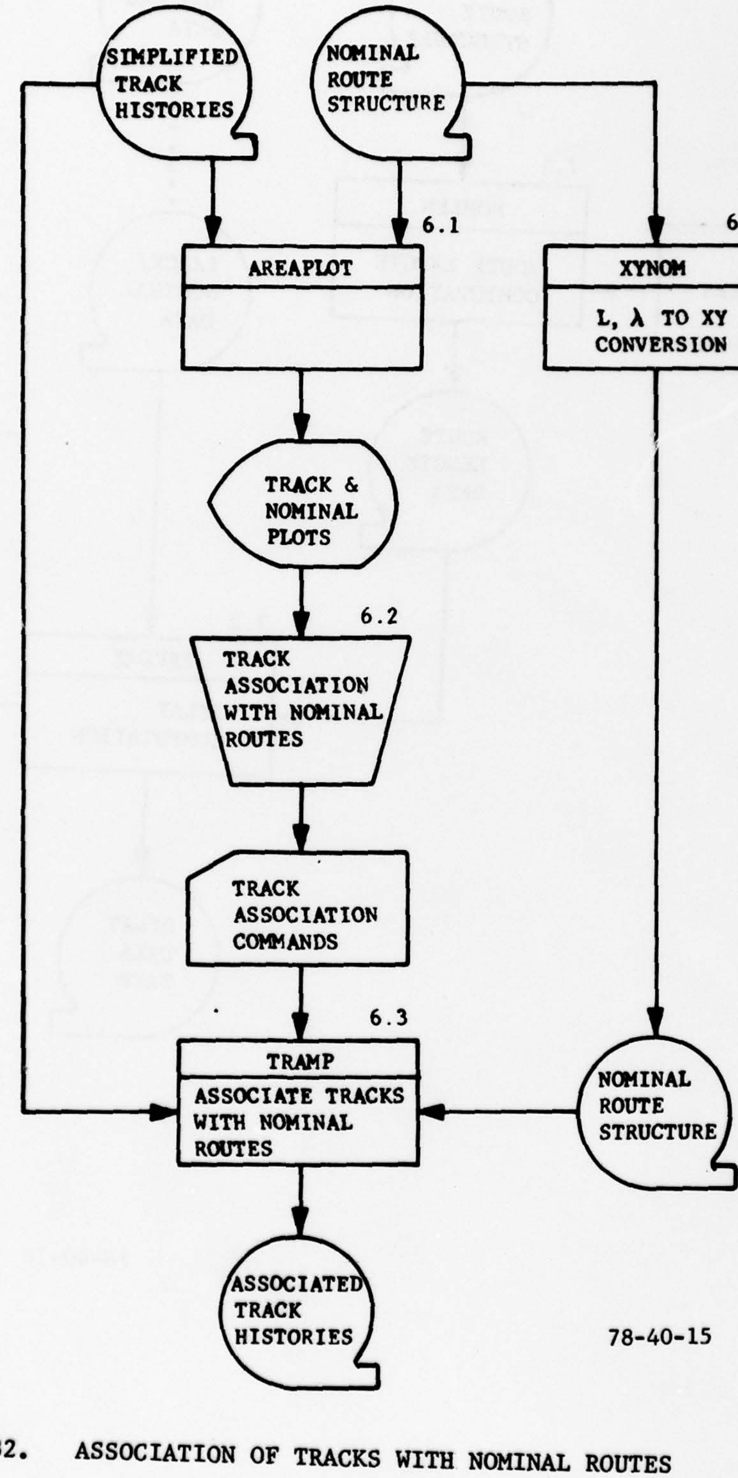


FIGURE 32. ASSOCIATION OF TRACKS WITH NOMINAL ROUTES

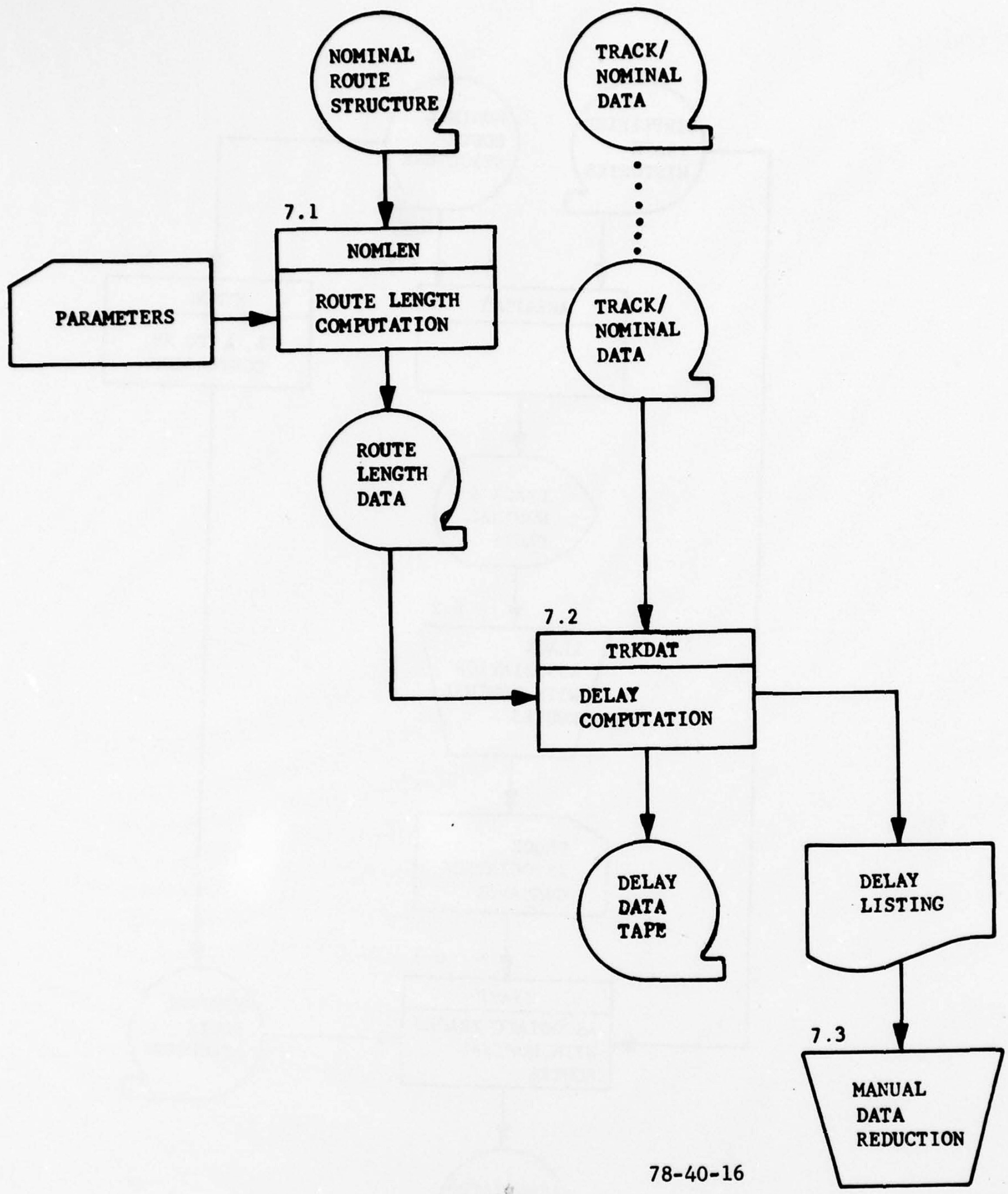


FIGURE 33. ROUTE MILEAGE AND DELAY COMPUTATION

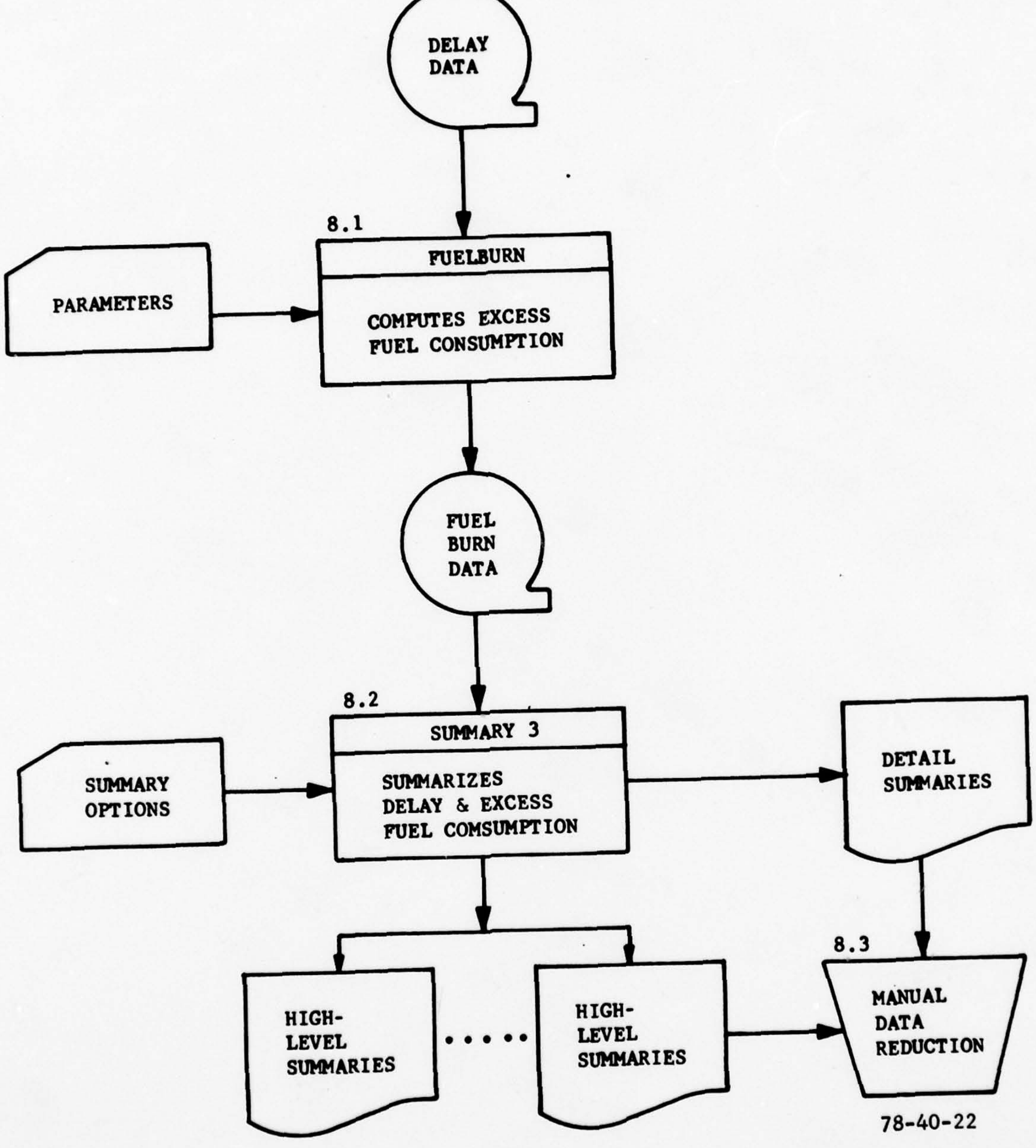


FIGURE 34. EXCESS FUEL COMPUTATION AND DATA SUMMARY

APPENDIX

Fuel Burn Summary 12 ORD Sample Hours

```
FUELBURN SUBSYSTEM
******************

PROGRAM:  (SUMMARY3)
FEBRUARY 3,1978


PROJECT: 011-001-230


AUTHORS:  RICHARD W. SOPER, ANA-220,
          THOMAS A. CHEYCE, ANA-220

NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER
ATLANTIC CITY, NEW JERSEY,  08405


FUELBURN ANALYSIS
-----------------

AREA= ORD
SAMPLE=  12
```

```
THE FOLLOWING FILES EXIST ON THE CURRENT DETAILED DATA BASE OUTPUT TAPE:

 1. NOMINAL/MINIMUM PATH DATA FILE:
   CHI XYNOM FROM 11:53 NOV 16,'77  12 SAMPLES      FUELFLOW DATE 22:48 MAR 16,'78

 2. DETAILED SAMPLE DATA FILE NO.  1;  COPIED FILE:
   CHI,I 1,    TRKDAT DATE 20:04 NOV 23,'77; TRAMP:ICHI I 1     MERGED  08:03 SEP 16,'77NPMS 15:45 JUL 15,'77 TRAMP 20:35 AUG 26,'77
     (THIS COPIED FILE WAS DETAILED DATA INPUT FILE NO.  1)

 3. DETAILED SAMPLE DATA FILE NO.  2;  COPIED FILE:
   CHI,I 2,    TRKDAT DATE 11:03 NOV 28,'77; TRAMP:ICHI I 2     TRACKS 12:40 APR 22,'77NPMS 22:36 SEP 21,'77 TRAMP 21:54 NOV 10,'77
     (THIS COPIED FILE WAS DETAILED DATA INPUT FILE NO.  2)

 4. DETAILED SAMPLE DATA FILE NO.  3;  COPIED FILE:
   CHI,I 3,    TRKDAT DATE 21:38 NOV 29,'77; TRAMP:ICHI I 3     TRACKS 17:52 APR 26,'77NPMS 22:48 AUG 26,'77 TRAMP 23:25 SEP 02,'77
     (THIS COPIED FILE WAS DETAILED DATA INPUT FILE NO.  3)

 5. DETAILED SAMPLE DATA FILE NO.  4;  COPIED FILE:
   CHI,V 1,    TRKDAT DATE 21:50 NOV 29,'77; TRAMP:ICHI V 1     TRACKS 15:00 SEP 07,'77NPMS 11:53 NOV 16,'77 TRAMP 13:29 NOV 22,'77
     (THIS COPIED FILE WAS DETAILED DATA INPUT FILE NO.  4)

 6. DETAILED SAMPLE DATA FILE NO.  5;  COPIED FILE:
   CHI,V 2,    TRKDAT DATE 22:11 NOV 29,'77; TRAMP:ICHA  V      TRACKS 10:29 SEP 20,'77NPMS 11:53 NOV 16,'77 TRAMP 18:05 NOV 28,'77
     (THIS COPIED FILE WAS DETAILED DATA INPUT FILE NO.  5)

 7. DETAILED SAMPLE DATA FILE NO.  6;  COPIED FILE:
   CHI,V 3,    TRKDAT DATE 22:25 NOV 29,'77; TRAMP:ICHI V 3     TRACKS 22:39 APR 28,'77NPMS 11:53 NOV 16,'77 TRAMP 17:44 NOV 28,'77
     (THIS COPIED FILE WAS DETAILED DATA INPUT FILE NO.  6)

 8. DETAILED SAMPLE DATA FILE NO.  7;  COPIED FILE:
   CHI,D 1,    TRKDAT DATE 21:45 NOV 30,'77; TRAMP:ICHI D 1     TRACKS 21:20 SEP 08,'77NPMS 22:36 SEP 21,'77 TRAMP 20:53 OCT 20,'77
     (THIS COPIED FILE WAS DETAILED DATA INPUT FILE NO.  7)

 9. DETAILED SAMPLE DATA FILE NO.  8;  COPIED FILE:
   CHI,D 2,    TRKDAT DATE 22:02 NOV 30,'77; TRAMP:ICHI D 2     MERGED  23:53 SEP 22,'77NPMS 15:45 JUL 15,'77 TRAMP 21:53 AUG 26,'77
     (THIS COPIED FILE WAS DETAILED DATA INPUT FILE NO.  8)

10. DETAILED SAMPLE DATA FILE NO.  9;  COPIED FILE:
   CHI,D 3,    TRKDAT DATE 22:14 NOV 30,'77; TRAMP:ICHI D 3     MERGED  17:54 SEP 26,'77NPMS 15:45 JUL 15,'77 TRAMP 22:20 AUG 26,'77
     (THIS COPIED FILE WAS DETAILED DATA INPUT FILE NO.  9)

11. DETAILED SAMPLE DATA FILE NO. 10;  COPIED FILE:
   CHI,N 1,    TRKDAT DATE 22:32 NOV 30,'77; TRAMP:ICHI N 1     MERGED  18:26 SEP 27,'77NPMS 22:48 AUG 26,'77 TRAMP 13:58 SEP 01,'77
```

```
     (THIS CEPIED FILE WAS CETAILED DATA INPLT FILE NO. 10)

 12. CETAILEC SAMPLE DATA FILE NO. 11;  COPIED FILE:
   CHION 2,   TRKDAT DATE 22:30 CEC 01,'77; TRAPPIICHI N 2    MERGED  18:53 SEP 27,'77MPPS 22:48 ALG 26,'77 TRAMP 13:25 SEP 01,'77
     (THIS CEPIED FILE WAS CETAILED DATA INPLT FILE NO. 11)

 13. CETAILEC SAMPLE DATA FILE NO. 12;  COPIED FILE:
   CHION 3,   TRKDAT DATE 22:57 CEC 01,'77; TRAPPIICHI N 3    MERGED  09:52 SEP 28,'77MPPS 22:48 ALG 26,'77 TRAMP 21:43 AUG 30,'77
     (THIS CEPIED FILE WAS CETAILED DATA INPUT FILE NO. 12)

     635 TRACKS HAVE BEEN LCACEC FROM 12 SAMPLES

     635 ASSIGNED TRACKS, ANC

       0 DELETED TRACKS WITH FELCING.
```

*** SUMMARY BY NOMINAL OF THE TRACKS ASSIGNED TO EACH NOMINAL ***   SAMPLE : ORD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, F 1, C 2, C 3, N 1, N 2, N 3,

NOMINAL..ORDAO2BV, PAIR..ORDARR, RNWY..A27L, TYPE..B, ADJMIN 55.890, ADJNOM 64.373, INCR 8.483 15.2%

OF TRACKS 2   .3 % OF ORD ASSIGNED TRACKS   0 HAVE HOLDING : 0 TYPE A/B 0 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	27.829	792	24.863	714	2.966	77	24.863	714	.000		0	.000		0
AVE	31.070	1006	26.581	858	4.489	148	26.581	858	.000		0	.000		0
TOTAL	62.140	2013	53.162	1716	8.978	297	53.162	1716	.000		0	.000		0

NOMINAL..ORDAO3BV, PAIR..ORDARR, RNWY..A27L, TYPE..B, ADJMIN 57.375, ADJNOM 61.209, INCR 3.833 6.7%

OF TRACKS 4   .6 % OF ORD ASSIGNED TRACKS   0 HAVE HOLDING : 0 TYPE A/B 0 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	9.336	419	9.223	383	.572	76	9.223	383	.000		0	.000		0
AVE	16.994	676	13.516	547	3.078	129	13.916	547	.000		0	.000		0
TOTAL	67.976	2706	55.665	2188	12.311	517	55.665	2188	.000		0	.000		0

NOMINAL..ORDAO4BV, PAIR..ORDARR, RNWY..A27L, TYPE..B, ADJMIN 61.898, ADJNOM 62.695, INCR .797 1.3%

OF TRACKS 2   .3 % OF ORD ASSIGNED TRACKS   0 HAVE HOLDING : 0 TYPE A/B 0 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	7.261	151	7.058	146	.204	5	7.058	146	.000		0	.000		0
AVE	32.478	1068	31.906	1050	.572	18	31.906	1050	.000		0	.000		0
TOTAL	64.955	2137	63.811	2100	1.144	37	63.811	2100	.000		0	.000		0

*** SUMMARY BY NOMINAL OF THE TRACKS ASSIGNED TO EACH NOMINAL ***   SAMPLE : ORD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, C 2, C 3, N 1, N 2, N 3,

NOMINAL..ORDA078V, PAIR..ORCARR, RNWY..A27L, TYPE..T, ADJMIN 78.620, ADJNOM 81.077, INCR 2.457 3.1%

OF TRACKS 1   .2 % OF ORD ASSIGNED TRACKS   1 HAVE HOLDING : 0 TYPE A/6 1 TYPE B

	TRK.OVER.CMIN		TRK.OVER.CNOM		CNOM.OVER.CMIN		PATH.STRETCH		TYPE 'A' HOLDING			TYPE 'B' HOLDING		
	NM	LBS	NM	LBS	NM	LBS	NM	LBS	NM	TIME	LBS	NM	TIME	LBS
ST.DEV	.000	0	.000	0	.000	0	.000	0	.000		0	.000		0
AVE	12.722	509	11.390	456	1.332	53	44.926	1479	.000		0	32.836	8:00	1023
TOTAL	12.722	509	11.390	456	1.332	53	44.926	1479	.000		0	32.836	8:00	1023

NOMINAL..ORDV01AV, PAIR..ORCARR, RNWY..A14L, TYPE..B, ADJMIN 66.334, ADJNOM 68.188, INCR 1.854 2.8%

OF TRACKS 44   6.9 % OF ORD ASSIGNED TRACKS   20 HAVE HOLDING : 15 TYPE A/6 5 TYPE B

	TRK.OVER.CMIN		TRK.OVER.CNOM		CNOM.OVER.CMIN		PATH.STRETCH		TYPE 'A' HOLDING			TYPE 'B' HOLDING		
	NM	LBS	NM	LBS	NM	LBS	NM	LBS	NM	TIME	LBS	NM	TIME	LBS
ST.DEV	7.408	497	7.425	466	.077	38	28.030	892	21.335	4:25	832	10.468	2:28	300
AVE	11.190	485	9.419	418	1.771	67	33.155	1134	63.859	14:56	1941	17.297	4:10	475
TOTAL	492.363	21375	414.442	18412	77.921	2962	1458.812	49908	957.884	344:04	29117	86.486	20:50	2378

NOMINAL..ORDV02AV, PAIR..ORCARR, RNWY..A14L, TYPE..T, ADJMIN 74.735, ADJNOM 77.442, INCR 2.706 3.6%

OF TRACKS 37   5.8 % OF ORD ASSIGNED TRACKS   1 HAVE HOLDING : 1 TYPE A/6 0 TYPE B

	TRK.OVER.CMIN		TRK.OVER.CNOM		CNOM.OVER.CMIN		PATH.STRETCH		TYPE 'A' HOLDING			TYPE 'B' HOLDING		
	NM	LBS	NM	LBS	NM	LBS	NM	LBS	NM	TIME	LBS	NM	TIME	LBS
ST.DEV	9.446	543	9.006	534	.557	33	12.427	780	.000		0	.000		0
AVE	18.171	770	17.288	734	.883	36	18.433	809	42.387	17:02	2781	.000		0
TOTAL	672.[illegible]	28520	639.662	27177	32.680	1343	682.039	29958	42.387	17:02	2781	.000		0

*** SUMMARY BY NOMINAL OF THE TRACKS ASSIGNED TO EACH NOMINAL *** SAMPLE : GRD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, D 1, D 2, D 3, N 1, N 2, N 3,

NOMINAL..GRDV03AV, PAIR..CRCARR, RNWY..A14L, TYPE..T, ADJMIN 75.882, ADJNOM 76.140, INCR .258 .3%

OF TRACKS 6 .5 % OF GRC ASSIGNED TRACKS — 0 HAVE HOLDING : 0 TYPE A/S 0 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	5.387	252	5.345	249	.065	3	5.345	249	.000		0	.000		0
AVE	17.499	598	17.368	593	.131	4	17.368	593	.000		0	.000		0
TOTAL	104.995	3590	104.210	3561	.785	28	104.210	3561	.000		0	.000		0

NOMINAL..GRDV04AV, PAIR..CRCARR, RNWY..A14L, TYPE..T, ADJMIN 77.893, ADJNOM 79.773, INCR 1.880 2.4%

OF TRACKS 13 2.0 % OF GRC ASSIGNED TRACKS — 1 HAVE HOLDING : 1 TYPE A/S 0 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	11.130	363	11.348	364	.605	19	19.978	496	.000		0	.000		0
AVE	13.748	389	12.259	348	1.489	41	16.490	423	53.704	12:30	974	.000		0
TOTAL	178.720	5060	159.369	4526	19.351	533	213.873	5501	53.704	12:30	974	.000		0

NOMINAL..GRD001AV, PAIR..CRCARR, RNWY..A14L, TYPE..B, ADJMIN 71.968, ADJNOM 72.018, INCR .050 .1%

OF TRACKS 33 5.2 % OF GRC ASSIGNED TRACKS — 15 HAVE HOLDING : 0 TYPE A/S 15 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	6.430	479	6.431	478	.002	1	21.630	846	.000		0	19.028	4146	839
AVE	10.588	491	10.540	489	.048	2	23.914	903	.000		0	29.422	6183	911
TOTAL	349.395	16209	347.819	16141	1.576	67	789.150	29813	.000		0	441.331	143128	13678

*** SUMMARY BY NOMINAL OF THE TRACKS ASSIGNED TO EACH NOMINAL *** SAMPLE : ORD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, C 2, C 3, N 1, N 2, N 3,

NOMINAL..ORD001BV, PAIR..ORDARR, RNWY..A27R, TYPE..B, ADJMIN 55.494, ADJNOM 64.371, INCR 8.877 16.0%

OF TRACKS 64 10.1 % OF ORD ASSIGNED TRACKS — 4 HAVE HOLDING : 2 TYPE A/B 2 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	9.286	884	9.465	719	1.042	210	11.929	822	13.678	3:10	1821	12.168	2:28	189
AVE	18.170	778	10.386	484	7.804	293	12.946	577	30.630	7:45	1982	29.545	6:47	974
TOTAL	1162.903	49817	663.425	31019	499.478	18798	783.974	36934	61.259	15:30	3568	59.090	13:34	1949

NOMINAL..ORD002AV, PAIR..ORDARR, RNWY..A14L, TYPE..T, ADJMIN 83.364, ADJNOM 86.419, INCR 3.055 3.7%

OF TRACKS 19 3.0 % OF ORD ASSIGNED TRACKS. — 3 HAVE HOLDING : 1 TYPE A/B 2 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	6.854	449	5.528	414	.684	40	9.932	482	.000		0	8.523	2:10	270
AVE	16.011	583	14.743	538	1.269	45	18.287	614	25.754	9:00	188	20.790	5:02	634
TOTAL	304.217	11083	280.110	10228	24.107	855	347.444	11682	25.754	9:00	188	41.580	10:04	1269

NOMINAL..ORD002BV, PAIR..ORDARR, RNWY..A32L, TYPE..S, ADJMIN 55.746, ADJNOM 58.709, INCR 2.963 5.3%

OF TRACKS 20 3.1 % OF ORD ASSIGNED TRACKS — 0 HAVE HOLDING : 0 TYPE A/B 0 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	14.256	673	14.261	648	.659	56	14.961	648	.000		0	.000		0
AVE	12.070	419	9.602	338	2.468	81	9.602	338	.000		0	.000		0
TOTAL	241.395	8396	192.043	6763	49.352	1632	192.043	6763	.000		0	.000		0

*** SUMMARY BY NOMINAL OF THE TRACKS ASSIGNED TO EACH NOMINAL ***   SAMPLE : ORD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, D 2, C 3, N 1, N 2, N 3,

NOMINAL..ORD003AV, PAIR..ORDARR, RNWY..A14L, TYPE..T, ADJMIN 84.801, ADJNOM 85.118, INCR .316 .4%

# OF TRACKS 8 1.3 % OF ORD ASSIGNED TRACKS	TRK.OVER.CMIN		TRK.OVER.CNOM		CNOM.OVER.CMIN		PATH.STRETCH		0 HAVE HOLDING : 0 TYPE A&B 0 TYPE B TYPE 'A' HOLDING			TYPE 'B' HOLDING		
	NM	LBS	NM	LBS	NM	LBS	NM	LBS	NM	TIME	LBS	NM	TIME	LBS
ST.DEV	2.556	302	2.551	300	.057	3	2.551	300	.000		0	.000		0
AVE	13.667	506	13.576	503	.090	3	13.576	503	.000		0	.000		0
TOTAL	109.334	4053	108.612	4025	.722	28	108.612	4025	.000		0	.000		0

NOMINAL..ORD003BV, PAIR..ORDARR, RNWY..A32L, TYPE..S, ADJMIN 54.996, ADJNOM 55.618, INCR .622 1.1%

# OF TRACKS 26 4.1 % OF ORD ASSIGNED TRACKS	TRK.OVER.CMIN		TRK.OVER.CNOM		CNOM.OVER.CMIN		PATH.STRETCH		0 HAVE HOLDING : 0 TYPE A&B 0 TYPE B TYPE 'A' HOLDING			TYPE 'B' HOLDING		
	NM	LBS	NM	LBS	NM	LBS	NM	LBS	NM	TIME	LBS	NM	TIME	LBS
ST.DEV	4.521	203	4.460	193	.176	11	4.460	193	.000		0	.000		0
AVE	6.018	202	5.531	185	.487	16	5.531	185	.000		0	.000		0
TOTAL	156.455	5262	143.796	4821	12.659	441	143.796	4821	.000		0	.000		0

NOMINAL..ORD004AV, PAIR..ORDARR, RNWY..A14L, TYPE..T, ADJMIN 86.866, ADJNOM 88.751, INCR 1.885 2.2%

# OF TRACKS 19 3.0 % OF ORD ASSIGNED TRACKS	TRK.OVER.CMIN		TRK.OVER.CNOM		CNOM.OVER.CMIN		PATH.STRETCH		2 HAVE HOLDING : 1 TYPE A&B 1 TYPE B TYPE 'A' HOLDING			TYPE 'B' HOLDING		
	NM	LBS	NM	LBS	NM	LBS	NM	LBS	NM	TIME	LBS	NM	TIME	LBS
ST.DEV	6.097	401	6.143	375	.293	32	26.988	841	.000		0	.000		0
AVE	14.902	570	13.124	507	1.778	62	19.448	693	117.104	27144	3012	3.049	1100	10
TOTAL	283.132	10838	249.353	9647	33.779	1190	369.406	13176	117.104	27144	3012	3.049	1100	10

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*** SUMMARY BY NOMINAL OF THE TRACKS ASSIGNED TO EACH NOMINAL *** SAMPLE : GRD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, C 2, C 3, N 1, N 2, N 3,

NOMINAL..GRD004BV, PAIR..CHCARR, RNWY..A32L, TYPE..S, ADJMIN 54.933, ADJNOM 55.895, INCR .962 1.8%

OF TRACKS 37 5.8 % OF GRC ASSIGNED TRACKS — 1 HAVE HOLDING : 1 TYPE A/A 0 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	5.065	161	5.068	158	.012	15	6.284	169	.000		0	.000		0
AVE	4.498	120	3.541	95	.957	24	4.228	108	25.429	6:00	464	.000		0
TOTAL	166.412	4464	131.001	3544	35.411	919	156.430	4009	25.429	6:00	464	.000		0

NOMINAL..GRD006AV, PAIR..CHCARR, RNWY..A14R, TYPE..T, ADJMIN 69.731, ADJNOM 80.448, INCR 10.717 15.4%

OF TRACKS 8 1.3 % OF GRC ASSIGNED TRACKS — 1 HAVE HOLDING : 1 TYPE A/A 0 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	3.626	366	3.539	185	1.447	227	10.435	390	.000		0	.000		0
AVE	17.674	477	8.471	226	9.203	251	11.326	313	22.842	5:32	696	.000		0
TOTAL	141.393	3822	67.769	1813	73.624	2009	90.611	2510	22.842	5:32	696	.000		0

NOMINAL..GRD006BV, PAIR..CHCARR, RNWY..A32L, TYPE..B, ADJMIN 64.067, ADJNOM 75.437, INCR 11.365 17.7%

OF TRACKS 18 2.8 % OF GRC ASSIGNED TRACKS — 1 HAVE HOLDING : 1 TYPE A/A 0 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	6.215	404	6.577	336	2.208	165	10.187	353	.000		0	.000		0
AVE	17.339	517	6.969	221	10.370	296	8.829	254	33.475	7:32	898	.000		0
TOTAL	312.102	9320	125.442	3984	186.660	5335	158.917	4580	33.475	7:32	898	.000		0

*** SUMMARY BY NOMINAL OF THE TRACKS ASSIGNED TO EACH NOMINAL *** SAMPLE : ORD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, r 1, D 2, D 3, N 1, N 2, N 3,

NOMINAL..ORD007AV, PAIR..ORDARR, RNWY..A14R, TYPE..T, ADJMIN 66.106, ADJNOM 75.127, INCR 9.021 13.6%

OF TRACKS 57 5.0 % OF ORD ASSIGNED TRACKS — 23 HAVE HOLDING : 6 TYPE A,& 17 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	7.878	672	7.870	522	.892	216	25.705	1123	31.563	7:17	1546	22.293	5:17	875
AVE	22.938	999	15.037	642	7.900	356	31.272	1192	50.249	12:28	1887	36.700	8:37	1177
TOTAL	1307.448	56972	857.128	36640	450.320	20332	1782.417	67979	301.496	114:50	11323	623.893	226:44	20015

NOMINAL..ORD007BV, PAIR..ORDARR, RNWY..A32L, TYPE..B, ADJMIN 66.727, ADJNOM 68.461, INCR 1.734 2.6%

OF TRACKS 51 8.0 % OF ORD ASSIGNED TRACKS — 16 HAVE HOLDING : 1 TYPE A,& 15 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	8.337	430	8.548	430	.716	29	15.995	633	.000		0	13.740	2:59	406
AVE	13.885	539	13.098	512	.788	27	20.027	701	41.377	9:00	708	20.801	4:54	595
TOTAL	708.150	27538	667.978	26126	40.172	1412	1021.376	35771	41.377	9:00	708	312.021	113:30	8936

NOMINAL..ORD008AV, PAIR..ORDARR, RNWY..A14R, TYPE..S, ADJMIN 55.338, ADJNOM 60.568, INCR 5.230 9.5%

OF TRACKS 22 3.5 % OF ORD ASSIGNED TRACKS — 4 HAVE HOLDING : 1 TYPE A,& 3 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	9.125	533	9.257	514	2.069	173	16.297	571	.000		0	29.737	5:12	478
AVE	9.912	478	6.314	279	3.598	199	11.779	391	34.091	7:42	387	28.714	6:37	500
TOTAL	218.057	10535	138.905	6154	79.152	4381	259.137	8611	34.091	7:42	387	86.141	19:52	1500

*** SUMMARY BY NOMINAL OF THE TRACKS ASSIGNED TO EACH NOMINAL *** SAMPLE : ORD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, C 2, C 3, N 1, N 2, N 3,

NOMINAL..ORCOO8BV, PAIR..ORLARR, RNWY..A27R, TYPE..T, ADJMIN 74.813, ADJNOM 80.955, INCR 6.142 8.2%

OF TRACKS 25 3.5 % OF ORD ASSIGNED TRACKS — 4 HAVE HOLDING : 4 TYPE A/S 0 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	9.563	1176	5.877	1088	1.177	161	12.544	1070	8.182	1:35	439	.000		0
AVE	14.917	758	9.404	552	5.353	205	13.912	669	27.172	7:16	726	.000		0
TOTAL	372.918	18972	235.101	13822	133.817	5149	347.788	16727	108.687	29:04	2904	.000		0

NOMINAL..ORCOO9AV, PAIR..ORLARR, RNWY..A14R, TYPE..S, ADJMIN 53.718, ADJNOM 54.737, INCR 1.019 1.9%

OF TRACKS 55 8.7 % OF ORD ASSIGNED TRACKS — 24 HAVE HOLDING : 0 TYPE A/S 24 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	8.064	489	7.968	481	.330	20	18.401	732	.000		0	13.259	31:05	394
AVE	7.714	379	7.250	358	.464	21	20.485	754	.000		0	30.332	7:01	907
TOTAL	424.264	20899	398.737	19726	25.527	1173	1126.494	41500	.000		0	727.957	248:34	21774

NOMINAL..ORCOO9BV, PAIR..ORLARR, RNWY..A27R, TYPE..T, ADJMIN 72.353, ADJNOM 75.133, INCR 2.779 3.8%

OF TRACKS 38 6.0 % OF ORD ASSIGNED TRACKS — 10 HAVE HOLDING : 8 TYPE A/S 2 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	12.903	679	12.522	650	.059	56	26.615	952	14.823	3:12	701	9.035	21:27	88
AVE	15.791	565	13.071	472	2.720	92	24.[illegible]	775	43.008	16:14	1053	41.202	9:46	1533
TOTAL	600.051	21478	496.694	17967	103.357	3510	923.460	29499	344.062	129:54	8425	82.404	19:32	3066

AD-A064 444 NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER ATL--ETC F/G 1/5
TERMINAL AREA DELAY AND FUEL CONSUMPTION ANALYSIS.(U)
JAN 79 A G HALVERSON, G JOLITZ

UNCLASSIFIED FAA-NA-78-40 FAA-EM-78-20 NL

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*** SUMMARY BY NOMINAL OF THE TRACKS ASSIGNED TO EACH NOMINAL *** SAMPLE : ORD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, C 2, C 3, N 1, N 2, N 3,

NOMINAL..ORDO1CAV, PAIR..ORDARR, RNWY..A14L, TYPE..S, ADJMIN 55.706, ADJNOM 60.861, INCR 5.155 9.3%

OF TRACKS 11 1.7 % OF ORD ASSIGNED TRACKS — 1 HAVE HOLDING : 1 TYPE A/S 0 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	6.244	47	5.685	42	1.883	13	9.427	58	.000		C	.000		0
AVE	4.665	32	2.757	18	1.908	13	-4.745	30	21.868	7:34	129	.000		0
TOTAL	51.314	359	30.329	207	20.985	152	52.197	336	21.868	7:34	129	.000		0

NOMINAL..ORDO1OBV, PAIR..ORDARR, RNWY..A27R, TYPE..B, ADJMIN 63.778, ADJNOM 64.091, INCR .313 .5%

OF TRACKS 15 2.4 % OF ORD ASSIGNED TRACKS — 0 HAVE HOLDING : 0 TYPE A/S 0 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	6.609	74	6.585	72	.139	2	6.485	72	.000		C	.000		0
AVE	8.728	80	8.612	78	.115	1	8.612	78	.000		0	.000		0
TOTAL	130.915	1200	129.186	1177	1.729	23	129.186	1177	.000		0	.000		0

*** SUMMARY BY NOMINAL TYPE *** SAMPLE : ORD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, M 1, C 2, C 3, N 1, N 2, N 3,

TYPE 'B' NOMINALS FOR THE AIRPORT ORC

OF TRACKS 233 36.7 % OF ORC ASSIGNED TRACKS — 56 HAVE HOLDING : 19 TYPE A, & 37 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	8.973	617	8.662	533	3.779	175	19.437	786	22.909	4:55	543	15.964	3:48	515
AVE	14.382	567	10.819	441	3.562	126	19.373	704	57.579	13:28	1809	24.295	5:42	728
TOTAL	3350.899	132320	2520.530	102867	829.969	29452	4513.852	164136	1093.995	416:06	34380	898.928	331:22	26942

TYPE 'S' NOMINALS FOR THE AIRPORT ORC

OF TRACKS 171 26.5 % OF ORC ASSIGNED TRACKS — 30 HAVE HOLDING : 3 TYPE A, & 27 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	8.391	441	8.235	422	1.430	89	15.073	587	6.286	0:56	416	14.379	3:14	414
AVE	7.356	291	6.052	241	1.305	50	11.288	386	27.129	7:05	516	30.152	6:58	862
TOTAL	1257.897	49919	1034.811	41218	223.086	8700	1930.297	66044	81.388	21:16	1550	814.098	308:26	23274

TYPE 'T' NOMINALS FOR THE AIRPORT ORC

OF TRACKS 231 36.4 % OF ORC ASSIGNED TRACKS — 46 HAVE HOLDING : 23 TYPE A, & 23 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOM NM	TRK.OVER.CNOM LBS	CNOM.OVER.CMIN NM	CNOM.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	9.456	675	9.251	594	3.091	184	20.992	909	25.473	4:52	1140	20.934	4:56	810
AVE	17.694	713	13.911	562	3.783	151	21.702	805	44.175	11:32	1339	34.077	8:03	1103
TOTAL	4087.262	164903	3213.388	129867	873.874	35035	5013.187	186084	1016.036	425:36	30804	783.762	305:20	25391

*** SUMMARY BY AIRPORT *** SAMPLE : ORD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, F 1, C 2, C 3, N 1, N 2, N 3,

ALL NOMINALS FOR THE AIRPORT ORD

OF TRACKS 635 100.0 % OF ORD ASSIGNED TRACKS — 132 HAVE HOLDING : 45 TYPE A, & 87 TYPE B

	TRK.OVER.CMIN		TRK.OVER.CNOM		CNOM.OVER.CMIN		PATH.STRETCH		TYPE 'A' HOLDING			TYPE 'B' HOLDING		
	NM	LBS	NM	LBS	NM	LBS	NM	LBS	NM	TIME	LBS	NM	TIME	LBS
ST.DEV	9.880	620	5.289	544	3.218	165	19.450	804	24.847	5128	1069	17.264	4103	595
AVE	13.695	546	10.660	431	3.035	115	18.043	655	48.698	12103	1483	28.699	6143	869
TOTAL	8696.059	347142	6769.129	273954	1926.929	73188	11457.936	416305	2191.419	902158	66741	2496.788	945108	75609

*** SUMMARY BY SECTOR ***   SAMPLE : ORD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, C 2, C 3, N 1, N 2, N 3,

SECTOR NE : ORDOC1AV ORDVC1AV ORD001BV ORD010BV

\# OF TRACKS 156   24.6 % OF ORD ASSIGNED TRACKS   39 HAVE HOLDING : 17 TYPE A,& 22 TYPE B

	TRK.OVER.CMIN		TRK.OVER.CNOM		CNOM.OVER.CMIN		PATH.STRETCH		TYPE 'A' HOLDING			TYPE 'B' HOLDING		
	NM	LBS	NM	LBS	NM	LBS	NM	LBS	NM	TIME	LBS	NM	TIME	LBS
ST.DEV	8.789	692	8.006	576	3.941	188	21.410	864	23.060	4:50	902	17.215	4:14	589
AVE	13.690	567	9.567	427	3.722	140	20.262	755	55.950	14:05	1948	26.678	6:16	818
TOTAL	2135.576	88603	1554.272	66751	580.704	21852	3160.922	117839	1019.143	359:34	33082	886.907	217:52	18006

SECTOR SE : ORDOC2AV ORDCC3AV ORD004AV ORDV02AV ORDV03AV ORDVC4AV ORD002BV ORDOC3BV ORDC04BV ORDA02BV
ORDAC3BV ORDAC4BV

\# OF TRACKS 193   30.4 % OF ORD ASSIGNED TRACKS   8 HAVE HOLDING : 5 TYPE A,& 3 TYPE B

	TRK.OVER.CMIN		TRK.OVER.CNOM		CNOM.OVER.CMIN		PATH.STRETCH		TYPE 'A' HOLDING			TYPE 'B' HOLDING		
	NM	LBS	NM	LBS	NM	LBS	NM	LBS	NM	TIME	LBS	NM	TIME	LBS
ST.DEV	10.029	475	9.838	458	.907	41	14.973	592	37.831	8:29	1477	11.884	2:47	404
AVE	12.498	456	11.239	416	1.198	40	12.900	463	52.876	14:27	1883	14.876	3:41	428
TOTAL	2412.063	88128	2180.784	80302	231.275	7825	2489.931	89506	264.378	112:16	7917	44.629	11:04	1286

SECTOR SW : ORDOC6AV ORDCC7AV ORDA07BV ORD006BV ORD007BV

\# OF TRACKS 135   21.3 % OF ORD ASSIGNED TRACKS   42 HAVE HOLDING : 9 TYPE A,& 33 TYPE B

	TRK.OVER.CMIN		TRK.OVER.CNOM		CNOM.OVER.CMIN		PATH.STRETCH		TYPE 'A' HOLDING			TYPE 'B' HOLDING		
	NM	LBS	NM	LBS	NM	LBS	NM	LBS	NM	TIME	LBS	NM	TIME	LBS
ST.DEV	8.625	583	8.246	472	4.035	221	81.486	909	26.879	6:22	1366	19.860	4:37	735
AVE	18.384	727	12.813	511	5.571	216	22.946	832	44.354	10:46	1480	29.386	6:54	908
TOTAL	2481.815	98164	1729.707	69022	752.108	29142	3097.647	112321	399.190	136:54	13324	968.750	348:14	29975

*** SUMMARY BY SECTOR *** SAMPLE : ORD 12

COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, n 1, D 2, C 3, N 1, N 2, N 3,

SECTOR NM : ORD008AV ORD009AV ORD010AV ORD008BV ORD009BV

\# OF TRACKS 151 23.8 % OF ORC ASSIGNED TRACKS — 43 HAVE HOLDING : 14 TYPE A, 29 TYPE B

	TRK.OVER.CMIN		TRK.OVER.CNOM		CNOM.OVER.CMIN		PATH.STRETCH		TYPE 'A' HOLDING			TYPE 'B' HOLDING		
	NM	LBS	NM	LBS	NM	LBS	NM	LBS	NM	TIME	LBS	NM	TIME	LBS
ST.DEV	10.431	703	10.147	657	2.044	124	19.801	831	14.183	3:10	610	14.248	3:14	435
AVE	11.037	478	8.634	383	2.403	95	17.940	639	36.336	9:35	886	30.914	7:10	908
TOTAL	1666.604	72246	1303.766	57878	362.838	14368	2708.976	96636	508.708	214:14	12417	896.502	327:58	26341

*** SUMMARY BY AIRCRAFT CATEGORY FOR CRC *** SAMPLE : CRC 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, M 1, C 2, C 3, N 1, N 2, N 3,

CATEGORY # 5

OF TRACKS 30 4.7 % OF CRC ASSIGNED TRACKS — 3 HAVE HOLDING : 1 TYPE A/6 2 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOP NM	TRK.OVER.CNOP LBS	CNOP.OVER.CMIN NM	CNOP.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	8.474	29	7.579	28	2.322	8	8.882	36	.000		C	1.502	0:42	11
AVE	8.772	30	7.076	24	1.696	5	8.079	30	21.868	7:34	129	4.111	1:30	25
TOTAL	263.153	917	212.281	742	50.872	175	242.371	922	21.868	7:34	129	8.222	3:00	50

CATEGORY # 6

OF TRACKS 76 12.0 % OF CRC ASSIGNED TRACKS — 8 HAVE HOLDING : 4 TYPE A/6 4 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOP NM	TRK.OVER.CNOP LBS	CNOP.OVER.CMIN NM	CNOP.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	9.203	65	7.536	56	3.406	24	11.041	75	9.306	9:03	4C	7.261	1:59	40
AVE	11.614	82	8.452	6C	3.161	22	10.426	73	24.984	8:24	171	12.521	3:39	74
TOTAL	882.638	6292	642.367	4590	240.271	1702	792.388	5574	99.936	33:36	684	50.085	14:36	299

CATEGORY # 8

OF TRACKS 5 .8 % OF CRC ASSIGNED TRACKS — 0 HAVE HOLDING : C TYPE A/6 0 TYPE B

	TRK.OVER.CMIN NM	TRK.OVER.CMIN LBS	TRK.OVER.CNOP NM	TRK.OVER.CNOP LBS	CNOP.OVER.CMIN NM	CNOP.OVER.CMIN LBS	PATH.STRETCH NM	PATH.STRETCH LBS	TYPE 'A' HOLDING NM	TYPE 'A' HOLDING TIME	TYPE 'A' HOLDING LBS	TYPE 'B' HOLDING NM	TYPE 'B' HOLDING TIME	TYPE 'B' HOLDING LBS
ST.DEV	3.799	21	3.783	21	.989	5	3.783	21	.000		C	.000		0
AVE	5.128	29	3.892	22	1.236	7	3.892	22	.000		0	.000		0
TOTAL	25.641	145	19.459	110	6.182	35	19.459	110	.000		C	.000		0

*** SUMMARY BY AIRCRAFT CATEGORY FOR GRD ***   SAMPLE : GRD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, r 1, D 2, C 3, N 1, N 2, N 3,

CATEGORY # 11

OF TRACKS 132 20.8 % OF GRD ASSIGNED TRACKS   29 HAVE HOLDING : 10 TYPE A,& 19 TYPE B

	TRK.OVER.CMIN NM	LBS	TRK.OVER.CNOP NM	LBS	CNOP.OVER.CMIN NM	LBS	PATH.STRETCH NM	LBS	TYPE 'A' HOLDING NM	TIME	LBS	TYPE 'B' HOLDING NM	TIME	LBS
ST.DEV	10.568	288	9.842	264	2.980	72	20.650	418	16.463	3:32	263	17.198	4:01	324
AVE	13.534	340	10.551	277	2.583	62	19.751	441	48.419	11:21	882	35.656	8:21	669
TOTAL	1786.494	44895	1446.456	36681	340.998	8213	2607.145	58228	484.193	153:30	8824	677.456	238:44	12723

CATEGORY # 13

OF TRACKS 232 36.8 % OF GRD ASSIGNED TRACKS   54 HAVE HOLDING : 22 TYPE A,& 32 TYPE B

	TRK.OVER.CMIN NM	LBS	TRK.OVER.CNOP NM	LBS	CNOP.OVER.CMIN NM	LBS	PATH.STRETCH NM	LBS	TYPE 'A' HOLDING NM	TIME	LBS	TYPE 'B' HOLDING NM	TIME	LBS
ST.DEV	9.385	379	9.128	362	3.342	121	20.123	633	27.014	6:06	763	17.121	4:01	818
AVE	14.292	535	10.593	418	3.299	116	19.751	681	48.074	11:38	1457	30.449	7:05	905
TOTAL	3315.766	124263	2890.408	97179	765.358	27084	4582.973	158198	1057.625	416:04	32057	974.239	346:48	28960

CATEGORY # 16

OF TRACKS 95 15.0 % OF GRD ASSIGNED TRACKS   22 HAVE HOLDING : 4 TYPE A,& 18 TYPE B

	TRK.OVER.CMIN NM	LBS	TRK.OVER.CNOP NM	LBS	CNOP.OVER.CMIN NM	LBS	PATH.STRETCH NM	LBS	TYPE 'A' HOLDING NM	TIME	LBS	TYPE 'B' HOLDING NM	TIME	LBS
ST.DEV	10.124	731	9.844	668	3.331	210	22.040	1047	24.806	3:25	894	19.886	4:50	813
AVE	16.364	1084	12.976	848	3.387	206	21.483	1193	73.482	19:11	3191	28.037	6:32	1108
TOTAL	1554.840	100224	1232.749	80632	321.791	19592	2031.348	113347	293.929	116:44	12766	504.670	187:44	19948

*** SUMMARY BY AIRCRAFT CATEGORY FOR ORD ***   SAMPLE : ORC 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, C 2, C 3, N 1, N 2, N 3,

CATEGORY # 17

OF TRACKS 55   8.7 % OF ORC ASSIGNED TRACKS   14 HAVE HOLDING : 3 TYPE A/& 11 TYPE B

	TRK.OVER.CMIN		TRK.OVER.CNCM		CNCM.OVER.CMIN		PATH.STRETCH		TYPE 'A' HOLDING			TYPE 'B' HOLDING		
	NM	LBS	NM	LBS	NM	LBS	NM	LBS	NM	TIME	LBS	NM	TIME	LBS
ST.DEV	9.178	620	9.032	626	2.890	189	19.563	1004	22.785	5:20	1058	8.497	1:51	369
AVE	11.768	791	9.243	629	2.525	162	17.408	1001	64.522	15:10	3002	23.228	5:15	1044
TOTAL	647.224	43543	508.338	34599	138.886	8943	957.416	55095	193.567	45:30	9008	255.511	57:46	11486

CATEGORY # 19

OF TRACKS 10   1.6 % OF ORC ASSIGNED TRACKS   2 HAVE HOLDING : 1 TYPE A/& 1 TYPE B

	TRK.OVER.CMIN		TRK.OVER.CNCM		CNCM.OVER.CMIN		PATH.STRETCH		TYPE 'A' HOLDING			TYPE 'B' HOLDING		
	NM	LBS	NM	LBS	NM	LBS	NM	LBS	NM	TIME	LBS	NM	TIME	LBS
ST.DEV	11.270	1616	11.909	1633	2.187	307	14.513	1625	.000		0	.000		0
AVE	22.060	2686	15.803	1941	6.257	744	22.494	2482	40.301	10:00	3270	26.605	6:30	2139
TOTAL	220.602	26860	158.031	19418	62.571	7441	224.937	24828	40.301	10:00	3270	26.605	6:30	2139

*** COUNTS BY AIRCRAFT TYPE *** SAMPLE : GND 12

COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, R 1, D 2, C 3, N 1, N 2, N 3,

CATEGORY #	A/C TYPE #	A/C TYPE #	A/C TYPE #	A/C TYPE #	A/C TYPE #	A/C TYPE #	A/C TYPE #	A/C TYPE #	A/C TYPE #	A/C TYPE #
5	BE9C 9	BE99 18	PU2 3							
	TOTAL = 30									
6	CV58 32	FA22 6	FA27 15	G159 2	C2 2	SW2 1	SW3 2	SW4 16		
	TOTAL = 76									
8	C500 2	H[illegible] 1	N265 2							
	TOTAL = 5									
11	B737 36	DC9 96								
	TOTAL = 132									
13	B727232									
	TOTAL = 232									
16	B707 67	DC8 28								
	TOTAL = 95									
17	DC10 43	L101 12								
	TOTAL = 55									
19	B747 10									
	TOTAL = 10									

*** SUMMARY OF TRACK HOLDING *** SAMPLE : ORD 12

COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, D 1, D 2, D 3, N 1, N 2, N 3,

132 ASSIGNED TRACKS HAVE HOLDING : 45 TYPE 'A', & 87 TYPE 'B'

	TYPE 'A' HOLDING NM	TIME	LBS	TYPE 'B' HOLDING NM	TIME	LBS
ST.DEV	24.847	5:28	1069	17.264	4:03	595
AVE	48.698	12:03	1483	28.699	6:43	869
TOTAL	2191.419	902:58	66741	2496.788	945:08	75609

*** ALTITUDE BAND SUMMARY OF HOLDING TYPE 'A' *** SAMPLE : ORD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, r 1, D 2, D 3, N 1, N 2, N 3,

ALTITUDE BAND	AVERAGE NM	AVERAGE TIME	AVERAGE LBS	TOTAL NM	TOTAL TIME	TOTAL LBS	A/C COUNT	
99999 ≥ x > 11499	65.571	16:29	1879	393.427	138:56	11276	6	* * * * * *
11500 ≥ x > 10999	25.625	6:00	740	25.625	6:00	740	1	*
11000 ≥ x > 10499	81.915	17:30	2167	81.915	17:30	2167	1	*
10500 ≥ x > 9999	46.082	10:04	1156	138.247	30:12	3470	3	* * *
10000 ≥ x > 9499	48.094	11:30	1144	96.187	23:00	2289	2	* *
9500 ≥ x > 8999	59.721	14:47	2224	238.886	59:10	8897	4	* * * *
9000 ≥ x > 8499	45.011	11:00	1414	495.122	201:00	15564	11	* * * * * * * * * * *
8500 ≥ x > 7999	48.258	11:52	1642	386.068	135:02	13136	8	* * * * * * * *
8000 ≥ x > 7499	36.214	9:45	1381	144.855	39:00	5524	4	* * * *
7500 ≥ x > 6999	42.300	11:23	886	169.219	45:34	3545	4	* * * *
7000 ≥ x > 6499	.000		0	.000		0	0	
6500 ≥ x > 5999	21.868	7:34	129	21.868	7:34	129	1	*
6000 ≥ x > 5499	.000		0	.000		0	0	
5500 ≥ x > 4999	.000		0	.000		0	0	
5000 ≥ x > 4499	.000		0	.000		0	0	
4500 ≥ x > 3999	.000		0	.000		0	0	
4000 ≥ x > 3499	.000		0	.000		0	0	
3500 ≥ x > 2999	.000		0	.000		0	0	
3000 ≥ x > 2499	.000		0	.000		0	0	
2500 ≥ x > 1999	.000		0	.000		0	0	
2000 ≥ x > 1499	.000		0	.000		0	0	
1500 ≥ x > 0	.000		0	.000		0	0	
99999 ≥ x > 0	48.898	12:03	1483	2191.419	902:28	66741	45	

*** ALTITUDE BAND SUMMARY OF HOLDING TYPE 'B' ***   SAMPLE : ORD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, C 2, C 3, N 1, N 2, N 3,

ALTITUDE BAND	AVERAGE			TOTAL			A/C	
	NM	TIME	LBS	NM	TIME	LBS	COUNT	
99999 > x > 11499	.000		0	.000		0	0	
11500 > x > 10999	.000		0	.000		0	0	
11000 > x > 10499	.000		0	.000		0	0	
10500 > x > 9999	13.609	3:00	232	13.609	3:00	232	1	*
10000 > x > 9499	16.845	3:46	521	33.690	7:32	1043	2	* *
9500 > x > 8999	30.391	7:20	1165	121.564	29:22	4662	4	* * * *
9000 > x > 8499	16.421	4:03	463	82.106	20:16	2319	5	* * * * *
8500 > x > 7999	36.882	8:33	1084	184.412	42:48	5424	5	* * * * *
8000 > x > 7499	22.616	5:13	771	158.313	36:36	5400	7	* * * * * * *
7500 > x > 6999	26.122	6:07	851	705.292	245:22	22996	27	* *
7000 > x > 6499	32.714	7:41	941	687.002	241:38	19767	21	* *
6500 > x > 5999	33.913	7:50	1105	101.740	23:32	3315	3	* * *
6000 > x > 5499	35.083	8:03	1050	140.333	32:14	4200	4	* * * *
5500 > x > 4999	36.294	8:29	1003	145.176	33:56	4015	4	* * * *
5000 > x > 4499	47.170	10:38	864	94.339	21:16	1728	2	* *
4500 > x > 3999	.000		0	.000		0	0	
4000 > x > 3499	22.889	5:36	459	22.889	5:36	459	1	*
3500 > x > 2999	6.523	2:00	43	6.523	2:00	43	1	*
3000 > x > 2499	.000		0	.000		0	0	
2500 > x > 1999	.000		0	.000		0	0	
2000 > x > 1499	.000		0	.000		0	0	
1500 > x > 0	.000		0	.000		0	0	
99999 > x > 0	28.699	6:43	869	2496.788	945:08	75609	87	

* *** ALTITUDE BAND SUMMARY OF LEVEL FLIGHT *** SAMPLE ; BND 12.
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, D 1, D 2, D 3, N 1, N 2, N 3,

ALTITUDE BAND	AVERAGE NM	AVERAGE TIME	AVERAGE LBS	TOTAL NM	TOTAL TIME	TOTAL LBS	A/C COUNT
99999 > X > 11499	24.750	5:42	619	123.750	28:30	3095	5
11500 > X > 10999	12.613	2:30	265	37.840	7:30	797	3
11000 > X > 10499	20.625	4:45	501	41.250	9:30	1003	2
10500 > X > 9999	18.256	3:46	695	310.360	104:14	11821	17
10000 > X > 9499	21.874	5:13	742	196.870	47:00	6681	9
9500 > X > 8999	16.599	4:08	531	182.590	45:38	5850	11
9000 > X > 8499	18.489	4:10	744	351.290	119:20	14151	19
8500 > X > 7999	28.477	6:38	913	1053.660	405:50	33789	37
8000 > X > 7499	28.803	7:07	852	1382.830	541:56	40898	48
7500 > X > 6999	26.265	7:03	821	2442.630	1066:36	76390	93
7000 > X > 6499	26.781	7:21	973	2222.860	1010:52	80777	83
6500 > X > 5999	32.867	9:18	1179	2562.820	1205:34	91998	78
6000 > X > 5499	34.073	10:18	1195	3066.540	1523:40	107597	90
5500 > X > 4999	33.033	10:04	1388	1618.900	813:58	68052	49
5000 > X > 4499	28.384	8:51	1322	879.910	434:50	41007	31
4500 > X > 3999	20.764	6:37	958	394.510	205:58	18208	19
4000 > X > 3499	11.438	4:02	511	125.820	44:26	5627	11
3500 > X > 2999	16.270	5:38	828	309.130	147:16	15682	19
3000 > X > 2499	16.927	5:24	1050	129.200	59:28	11557	11
2500 > X > 1999	.000		0	.000		0	0
2000 > X > 1499	.000		0	.000		0	0
1500 > X > 0	.000		0	.000		0	0
99999 > X > 0	27.828	7:42	999	17678.762	8132:06	634988	638

*** MILEAGE OVER NOMINAL SUMMARY BY COUNT *** SAMPLE : RND 12

COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, D 1, D 2, D 3, N 1, N 2, N 3,

MILEAGE BAND	AVERAGE NM	AVERAGE LBS	TOTAL NM	TOTAL LBS	A/C COUNT
99999 > X > 51	.000	0	.000	0	0
51 > X > 48	48.934	2372	48.934	2372	1
48 > X > 45	.000	0	.000	0	0
45 > X > 42	42.819	1275	128.457	3827	3
42 > X > 39	40.505	2160	162.018	8642	4
39 > X > 36	37.580	2230	150.319	8922	4
36 > X > 33	34.369	709	34.369	709	1
33 > X > 30	31.010	799	186.061	4796	6
30 > X > 27	28.145	1304	450.320	20864	16
27 > X > 24	25.491	1265	560.805	27848	22
24 > X > 21	22.342	855	781.976	29942	35
21 > X > 18	19.485	795	837.869	34202	43
18 > X > 15	16.295	712	863.650	37771	53
15 > X > 12	13.307	475	785.113	28060	59
12 > X > 9	10.457	419	752.901	30173	72
9 > X > 6	7.457	262	559.280	19679	75
6 > X > 3	4.568	157	379.126	13105	83
3 > X > 0	.954	30	132.602	4247	139
0 > X > -3	-1.495	-45	-19.430	-591	13
-3 > X > -6	-4.207	-103	-25.241	-621	6
-6 > X > -9	.000	0	.000	0	0
-9 > X >-99999	.000	0	.000	0	0
99999 > X >-99999	10.650	431	6763.129	273954	635

*** MILEAGE OVER NOMINAL SUMMARY BY PERCENT ***   SAMPLE I AND 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, D 2, C 3, N 1, N 2, N 3,

MILEAGE BAND	AVERAGE NM	AVERAGE LBS	TOTAL NM	TOTAL LBS	A/C %	
99999 > X > 51	.000	0	.000	0	0	
51 > X > 48	48.934	2372	48.934	2372	0	
48 > X > 45	.000	0	.000	0	0	
45 > X > 42	42.819	1275	128.457	3827	0	
42 > X > 39	40.508	2160	162.018	8642	1	*
39 > X > 36	37.580	2230	150.319	8922	1	*
36 > X > 33	34.365	709	34.369	709	0	
33 > X > 30	31.010	799	186.061	4796	1	*
30 > X > 27	28.145	1304	450.320	20864	3	***
27 > X > 24	25.451	1265	560.805	27848	3	***
24 > X > 21	22.342	855	781.976	29942	6	******
21 > X > 18	19.485	795	837.869	34202	7	*******
18 > X > 15	16.290	712	863.850	37771	8	********
15 > X > 12	13.307	475	785.113	28060	9	*********
12 > X > 9	10.457	419	752.901	30173	11	***********
9 > X > 6	7.467	262	555.280	19679	12	************
6 > X > 3	4.568	157	379.126	13105	13	*************
3 > X > 0	.364	30	132.602	4247	22	**********************
0 > X > -3	-1.495	-45	-19.430	-591	2	**
-3 > X > -6	-4.207	-103	-25.241	-621	1	*
-6 > X > -9	.000	0	.000	0	0	
-9 > X > -99999	.000	0	.000	0	0	
99999 > X > -99999	10.880	431	6709.129	273994	100	

*** MILEAGE OVER NOMINAL SUMMARY BY SUMMED PERCENT ***   SAMPLE : END 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, r 1, D 2, D 3, A 1, A 2, A 3,

MILEAGE BAND		AVERAGE NM	AVERAGE LBS	TOTAL NM	TOTAL LBS	A/C %	
99999 ≥ X >	51	.000	0	.000	0	0	
51 ≥ X >	48	48.934	2372	48.934	2372	0	
48 ≥ X >	45	48.934	2372	48.934	2372	0	
45 ≥ X >	42	44.342	1550	177.391	6200	1	*
42 ≥ X >	39	42.426	1855	339.409	14842	1	*
39 ≥ X >	36	40.811	1980	489.728	23765	2	*
36 ≥ X >	33	40.315	1882	524.097	24475	2	*
33 ≥ X >	30	37.377	1540	710.158	29271	3	**
30 ≥ X >	27	33.157	1432	1160.478	50136	6	***
27 ≥ X >	24	30.198	1368	1721.283	77984	9	*****
24 ≥ X >	21	27.203	1173	2503.259	107927	14	*******
21 ≥ X >	18	24.743	1092	3341.128	142129	21	***********
18 ≥ X >	15	22.366	956	4204.778	179901	30	***************
15 ≥ X >	12	20.202	841	4989.891	207961	39	********************
12 ≥ X >	9	18.002	746	5742.792	238135	50	*************************
9 ≥ X >	6	16.995	684	6302.072	267814	62	*******************************
6 ≥ X >	3	14.007	567	6681.198	270919	75	**************************************
3 ≥ X >	0	11.061	446	6813.800	275167	97	***
0 ≥ X >	-3	10.802	436	6794.370	274976	99	**
-3 ≥ X >	-6	10.660	431	6769.129	273954	100	**
-6 ≥ X >	-9	10.660	431	6769.129	273954	100	**
-9 ≥ X >	-99999	10.660	431	6769.129	273954	100	**
99999 ≥ X >	-99999	10.660	431	6769.129	273984	100	

*** EXCESS FUEL SUMMARY BY COUNT *** SAMPLE : GRD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, D 2, D 3, N 1, N 2, N 3,

FUELBURN BAND	AVERAGE NM	AVERAGE LBS	TOTAL NM	TOTAL LBS	A/C COUNT	
99995 > x > 2000	30.873	2736	339.598	30099	11	***********
200C > x > 1900	23.056	1947	46.112	3895	2	**
190C > x > 1800	23.207	1845	116.036	9228	5	*****
180C > x > 1700	26.955	1748	107.818	6992	4	****
170C > x > 1600	22.547	1650	67.642	4952	3	***
160C > x > 1500	23.340	1546	163.378	10826	7	*******
150C > x > 1400	22.752	1464	113.761	7323	5	*****
140C > x > 1300	23.795	1368	261.743	15048	11	***********
130C > x > 1200	23.988	1249	167.914	8748	7	*******
120C > x > 1100	27.228	1153	299.512	12688	11	***********
110C > x > 1000	19.805	1044	217.854	11484	11	***********
100C > x > 900	20.966	942	251.591	11314	12	************
90C > x > 800	19.129	854	363.457	16229	19	*******************
80C > x > 700	18.680	746	429.636	17161	23	***********************
70C > x > 600	15.735	644	456.312	18690	29	*****************************
60C > x > 500	15.962	552	590.583	20460	37	*************************************
50C > x > 400	12.627	445	542.976	19135	43	***
40C > x > 300	10.280	345	637.703	21434	62	**
30C > x > 200	8.256	246	412.815	12321	50	**
20C > x > 100	8.264	149	636.364	11508	77	**
10C > x > 0	3.515	36	597.495	6133	170	**
C > x >=-99999	-11.421	-39	-411.171	-1435	36	************************************
99999 > x >=-99999	10.660	431	6765.125	273964	635	

*** EXCESS FUEL SUMMARY BY PERCENT *** SAMPLE : GRD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, D 1, D 2, D 3, N 1, N 2, N 3,

FUELBURN BAND	AVERAGE NM	AVERAGE LBS	TOTAL NM	TOTAL LBS	A/C %	
99999 > X > 2000	30.873	2736	339.598	30099	2	**
2000 > X > 1900	23.056	1947	46.112	3895	0	
1900 > X > 1800	23.207	1845	116.036	9228	1	*
1800 > X > 1700	26.955	1748	107.818	6992	1	*
1700 > X > 1600	22.547	1650	67.642	4952	0	
1600 > X > 1500	23.340	1546	163.378	10826	1	*
1500 > X > 1400	22.752	1464	113.761	7323	1	*
1400 > X > 1300	23.795	1368	261.743	15048	2	**
1300 > X > 1200	23.988	1249	167.914	8748	1	*
1200 > X > 1100	27.238	1153	299.612	12688	2	**
1100 > X > 1000	19.805	1044	217.854	11484	2	**
1000 > X > 900	20.966	942	251.591	11314	2	**
900 > X > 800	19.129	854	363.457	16229	3	***
800 > X > 700	18.680	746	429.636	17161	4	****
700 > X > 600	15.735	644	456.312	18690	5	*****
600 > X > 500	15.362	582	590.583	20480	6	******
500 > X > 400	12.627	445	542.976	19135	7	*******
400 > X > 300	10.286	346	637.703	21434	10	**********
300 > X > 200	8.256	246	412.815	12331	8	********
200 > X > 100	8.264	145	636.364	11208	12	************
100 > X > 0	3.515	36	597.495	6133	27	***************************
0 > X >-99999	-1.421	-39	-51.171	-1435	6	******
99999 > X >-99999	10.660	431	6789.129	273984	100	

*** EXCESS FUEL SUMMARY BY SLPPED PERCENT ***   SAMPLE : ORD 12
COMMENTS : CHI SAPFLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, C 2, C 3, A 1, A 2, A 3,

FUELBURN BAND	AVERAGE NM	AVERAGE LBS	TOTAL NM	TOTAL LBS	A/C %	
99995 > X > 2000	30.873	2736	339.598	30099	2	*
200C > X > 1900	29.67C	2615	385.710	33995	2	*
19CC > X > 1800	27.875	24C1	501.746	43224	3	**
18CC > X > 1700	27.7C7	2222	609.564	5C216	3	**
17CC > X > 1600	27.088	2206	677.206	55169	4	**
16CC > X > 1500	26.268	2C62	840.584	65995	5	***
15CC > X > 1400	25.793	1981	954.345	73319	6	***
14CC > X > 1300	25.335	184C	1216.088	88367	8	****
13CC > X > 1200	25.164	1765	1384.002	97116	9	*****
12CC > X > 1100	25.5C8	1663	1683.514	109804	10	*****
11CC > X > 1000	24.693	1575	1901.368	121289	12	******
10CC > X > 900	24.191	1489	2152.959	132604	14	*******
9CC > X > 800	23.3CC	1378	2516.416	148834	17	*********
8CC > X > 700	22.483	1267	2946.052	165995	21	***********
7CC > X > 600	21.265	1154	34C2.364	184686	25	*************
6CC > X > 500	20.263	1C41	3992.947	205146	31	****************
5CC > X > 400	18.9CC	934	4535.923	224282	38	*******************
4CC > X > 300	17.131	813	5173.626	245716	48	************************
3CC > X > 200	15.871	733	5586.441	258048	55	****************************
2CC > X > 100	14.5C5	627	6222.805	263256	68	**********************************
1CC > X > 0	11.386	489	6820.300	275389	94	***
C > X >-99999	10.66C	431	6769.129	273984	100	**
99995 > X >-99999	10.66C	431	6769.129	273984	100	

*** PATHSTRETCH FUEL SUMMARY BY COLAT *** SAMPLE : BRD 12

COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, C 2, C 3, A 1, A 2, A 3,

FUELBURN BAND	AVERAGE NM	AVERAGE LBS	TOTAL NM	TOTAL LBS	A/C COUNT	
9999S > X > 3000	74.C22	3965	1110.336	59479	15	***************
300C > X > 2850	58.982	291C	117.964	5820	2	**
285C > X > 2700	48.616	2739	97.232	5479	2	**
270C > X > 2550	83.549	2692	83.549	2692	1	*
255C > X > 2400	57.833	244C	173.498	7321	3	***
240C > X > 2250	49.861	2323	299.164	13942	6	******
225C > X > 2100	55.368	2175	387.575	15230	7	*******
210C > X > 1950	38.1C1	2C22	190.503	1C114	5	*****
195C > X > 1800	35.488	1868	319.391	16819	9	*********
180C > X > 1650	48.159	1708	389.273	13665	8	********
165C > X > 1500	42.826	1567	642.383	23519	15	***************
150C > X > 1350	30.6C5	1414	459.133	21213	15	***************
135C > X > 1200	34.586	1273	1141.322	42039	33	*********************************
120C > X > 1050	32.795	1135	688.690	23850	21	*********************
105C > X > 900	25.532	979	587.230	22533	23	***********************
90C > X > 750	24.832	835	1018.108	34257	41	***
75C > X > 600	17.555	670	737.303	28153	42	**
60C > X > 450	15.342	524	797.762	27260	52	**
45C > X > 300	12.55C	360	728.506	20932	58	**
30C > X > 150	10.312	215	680.592	14243	66	**
15C > X > 0	4.927	51	876.959	9095	178	***
C > X >-99999	-1.489	-41	-49.137	-1361	33	*********************************
99999 > X >-99999	18.043	656	11457.336	416305	635	

*** PATHSTRETCH FUEL SUMMARY BY PERCENT ***   SAMPLE : GRD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, D 1, D 2, D 3, A 1, A 2, A 3,

FUELBURN BAND	AVERAGE NM	AVERAGE LBS	TOTAL NM	TOTAL LBS	A/C %	
99999 > X > 3000	74.022	3965	1110.336	55479	2	**
3000 > X > 2850	58.982	2910	117.964	5820	0	
2850 > X > 2700	48.616	2739	97.232	5479	0	
2700 > X > 2550	83.549	2692	83.549	2692	0	
2550 > X > 2400	57.833	2440	173.498	7321	0	
2400 > X > 2250	49.861	2323	299.164	13942	1	*
2250 > X > 2100	55.368	2175	387.575	15230	1	*
2100 > X > 1950	38.101	2022	190.503	10114	1	*
1950 > X > 1800	39.488	1868	319.391	16819	1	*
1800 > X > 1650	46.189	1708	369.273	13665	1	*
1650 > X > 1500	42.826	1567	642.383	23519	2	**
1500 > X > 1350	30.605	1414	459.133	21213	2	**
1350 > X > 1200	34.086	1273	1141.322	42039	5	*****
1200 > X > 1050	38.795	1135	688.690	23860	3	***
1050 > X > 900	29.532	979	587.230	22533	4	****
900 > X > 750	24.832	835	1018.108	34287	6	******
750 > X > 600	17.555	670	737.303	28193	7	*******
600 > X > 450	18.342	524	797.762	27260	8	********
450 > X > 300	18.560	360	728.806	20932	9	*********
300 > X > 150	10.312	215	680.592	14243	10	**********
150 > X > 0	4.927	51	876.989	9095	28	****************************
0 > X >-99999	-1.489	-41	-49.137	-1361	5	*****
99999 > X >-99999	18.043	695	11487.336	418308	100	

*** PATHSTRETCH FUEL SUMMARY BY SUMMED PERCENT ***   SAMPLE : GRD 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, D 1, D 2, D 3, N 1, N 2, N 3,

FUELBURN BAND	AVERAGE NM	AVERAGE LBS	TOTAL NM	TOTAL LBS	A/C %	
99995 > X > 3000	74.022	3968	1110.336	59479	2	*
3000 > X > 2850	72.283	3841	1228.300	65300	3	**
2850 > X > 2700	69.765	3725	1326.532	70779	3	**
2700 > X > 2550	70.464	3673	1409.081	73471	3	**
2550 > X > 2400	68.808	3512	1582.579	80793	4	**
2400 > X > 2250	64.888	3266	1881.743	94736	5	***
2250 > X > 2100	63.037	3054	2269.318	109966	6	***
2100 > X > 1950	59.996	2928	2459.821	120080	6	***
1950 > X > 1800	56.584	2738	2779.212	136900	8	****
1800 > X > 1650	54.284	2695	3148.485	160866	9	*****
1650 > X > 1500	51.930	2384	3790.868	174085	11	******
1500 > X > 1350	48.295	2219	4290.001	198298	14	*******
1350 > X >. 1200	44.556	1961	5391.323	237338	19	**********
1200 > X > 1050	42.817	1839	6080.013	261188	22	***********
1050 > X > 900	40.408	1719	6667.243	283721	26	*************
900 > X > 750	37.308	1543	7686.361	317979	32	****************
750 > X > 600	33.362	1395	8422.654	346132	39	********************
600 > X > 450	30.735	1244	9220.416	373393	47	************************
450 > X > 300	27.790	1101	9948.922	394326	56	****************************
300 > X > 150	25.070	963	10629.814	408870	67	**********************************
150 > X > 0	19.114	693	11806.473	417666	95	**
0 > X >-99999	18.043	688	11497.336	418305	100	**
99995 > X >-99999	18.043	688	11497.336	418305	100	

*** ALTITUDE BAND SUMMARY BY PERCENT : (LEVEL FLIGHT/TRACK LENGTH)*100. *** SAMPLE : END 12
COMMENTS : CHI SAMPLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, D 2, C 3, N 1, N 2, N 3,

ALTITUDE BAND	AVERAGE NM	AVERAGE LBS	TOTAL NM	TOTAL LBS	A/C %
99999 > X > 12500	.0CC	C	.000	0	0
125CC > X > 12000	6.63C	17C	6.630	170	10
1200C > X > 11500	29.28C	731	117.120	2925	44
115CC > X > 11000	18.613	265	37.840	797	20
11CCC > X > 10500	20.625	5C1	41.250	1003	33
105CC > X > 10000	18.256	695	310.360	11821	29
10C0C > X > 9500	21.874	742	196.870	6681	34
95CC > X > 9000	16.595	531	182.590	5850	29
9CCC > X > 8500	18.483	744	351.290	14151	29
85CC > X > 8C00	28.477	913	1053.660	33789	40
80CC > X > 7500	28.8C5	852	1382.830	40898	40
75CC > X > 7000	26.268	821	2442.630	76390	40
70CC > X > 6500	28.721	973	2222.860	8C777	41
650C > X > 6000	32.867	1179	2562.820	91998	47
60CC > X > 5500	34.C73	1195	3066.540	1C7597	50
550C > X > 5000	35.035	1388	1618.900	68052	51
50CC > X > 4500	28.384	1322	879.910	41007	44
450C > X > 4000	20.764	958	394.510	18208	36
400C > X > 3500	11.438	811	125.820	5827	31
350C > X > 3000	16.27C	825	309.130	15682	42
300C > X > 2500	14.927	1090	175.200	11987	37
250C > X >-99999	.0CC	0	.000	0	0
99999 > X >-99999	27.828	995	17478.760	634988	42

*** ALTITUDE BAND SUMMARY BY PERCENT : (TRK-CNBM/CNBM)*100. ***   BAFFLE : GRD 12
COMMENTS : CHI BAFFLES : I 1, I 2, I 3, V 1, V 2, V 3, C 1, C 2, D 2, N 1, N 2, N 3,

ALTITUDE BAND	AVERAGE NM	AVERAGE LBS	TOTAL NM	TOTAL LBS	A/C %	
99995 ≥ X > 12500	.000	0	.000	0	0	
1250C ≥ X > 12000	3.438	88	3.438	88	5	*****
1200C ≥ X > 11500	3.806	97	15.223	389	6	******
1150C ≥ X > 11000	1.194	44	3.[illegible]1	132	2	**
1100C ≥ X > 10500	6.5C4	12C	13.[illegible]7	240	11	***********
1050C ≥ X > 10000	9.671	239	96.410	4065	10	**********
1000C ≥ X > 9500	7.174	275	64.568	2475	13	*************
950C ≥ X > 9000	3.537	107	38.907	1178	7	*******
900C ≥ X > 8500	4.847	226	92.092	4294	8	********
[illegible]C ≥ X > 8000	7.7C9	290	285.234	10732	12	************
[illegible]C ≥ X > 7500	9.54C	295	457.936	14197	15	***************
750C ≥ X > 7000	8.3C1	291	771.970	27091	15	***************
700C ≥ X > 6500	9.257	373	768.326	31030	17	*****************
650C ≥ X > 6000	14.4C7	530	1123.759	41402	26	**************************
600C ≥ X > 5500	14.034	540	1263.035	48601	26	**************************
[illegible]C ≥ X > 5000	16.333	776	825.737	38027	[illegible]	***********************************
[illegible]C ≥ X > 4500	14.129	748	437.997	23181	[illegible]	****************************
[illegible]C ≥ X > 4000	18.82C	[illegible]	237.878	[illegible]	27	***************************
4[illegible]C ≥ X > 3500	4.7C9	284	51.804	3127	14	**************
350C ≥ X > 3000	6.377	285	121.159	5430	20	********************
300C ≥ X > 2500	8.461	648	93.068	7138	25	*************************
[illegible] ≥ X >-99999	.000	0	.000	0	0	
[illegible] ≥ X >-99999	10.86C	431	6769.129	272[illegible]	20	

*** ALTITUDE BAND SUMMARY BY PERCENT : (TRK-CNGM/TRACK LENGTH)*100. *** SAMPLE : GRD 12
COMMENTS : CHI SAPPLES : I 1, I 2, I 3, V 1, V 2, V 3, D 1, D 2, D 3, N 1, N 2, N 3,

ALTITUDE BAND	AVERAGE NM	AVERAGE LBS	TOTAL NM	TOTAL LBS	A/C %	
99995 > x > 12500	.CCC	C	.000	0	0	
1250C > x > 12000	3.438	88	3.438	88	5	*****
1200C > x > 11500	3.8C6	97	15.223	389	6	******
1150C > x > 11000	1.194	44	3.581	132	2	**
110CC > x > 10500	6.5C4	12C	13.007	240	10	**********
1050C > x > 10000	8.671	239	96.410	4065	9	*********
1000C > x > 9500	7.174	275	64.568	2475	11	***********
950C > x > 9000	3.537	107	38.907	1178	6	******
900C > x > 8500	4.847	226	92.092	4294	8	********
850C > x > 8000	7.7C3	290	285.234	10732	11	***********
800C > x > 7500	9.54C	298	457.936	14197	13	*************
750C > x > 7000	8.3C1	291	771.970	27091	13	*************
700C > x > 6500	9.287	373	768.326	31030	14	**************
650C > x > 6000	14.4C7	530	1123.759	41402	21	*********************
600C > x > 5500	14.034	540	1263.035	48601	20	********************
550C > x > 5000	16.333	776	889.737	38027	26	**************************
500C > x > 4500	14.123	745	437.997	23101	22	**********************
450C > x > 4000	12.92C	589	237.878	11206	21	*********************
400C > x > 3500	4.7C3	284	91.804	3127	13	*************
350C > x > 3000	6.377	285	121.159	5430	17	*****************
300C > x > 2500	8.461	648	93.068	7138	20	********************
250C > x >-99999	.00C	0	.000	0	0	
99999 > x >-99999	10.660	431	6769.139	273984	16	

```
NOW LOADING THE NOMINAL PATH DATA FILE:
     CWI XYNOM FROM 11:03 NOV 16,'77  12 SAMPLES      FUELFLOW DATE 22:48 MAR 16,'78

THE FOLLOWING SAMPLES HAVE BEEN SELECTED FOR SUMMARIZATION:

*STOP* C
IFIN
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XDS SIGMA 5/7 BPM OPERATING SYSTEM   ** VERSION C03  **

NAME ................ CHEYCE
ACCOUNT ............. SUMMARY3

SIGN-OFF ............ 16:24 JUL 25,'78
TOTAL JOB TIME ...... 00:03:29
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